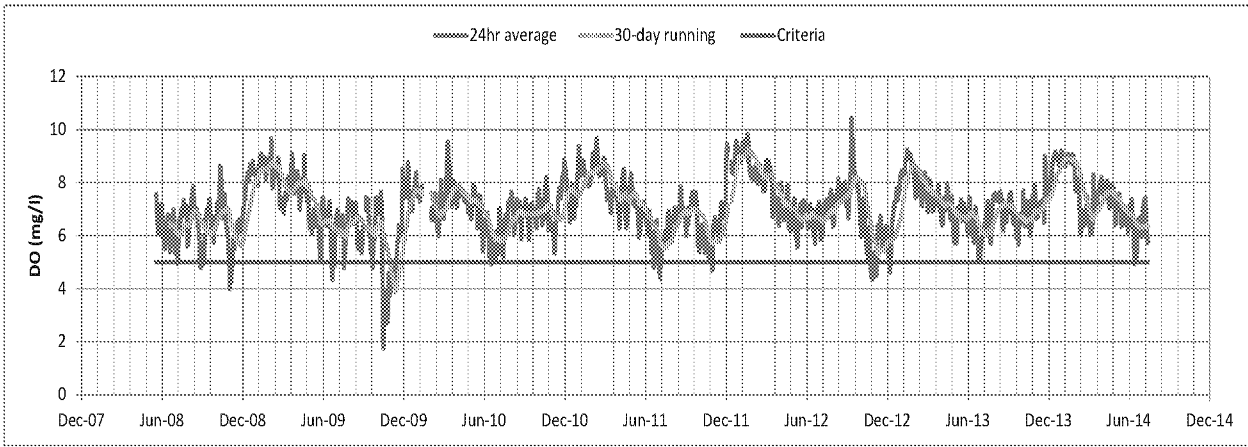

Figure B-41 24-hour running average and 30-day running average DO at First Mallard Slough compared to a target of 5 mg/L

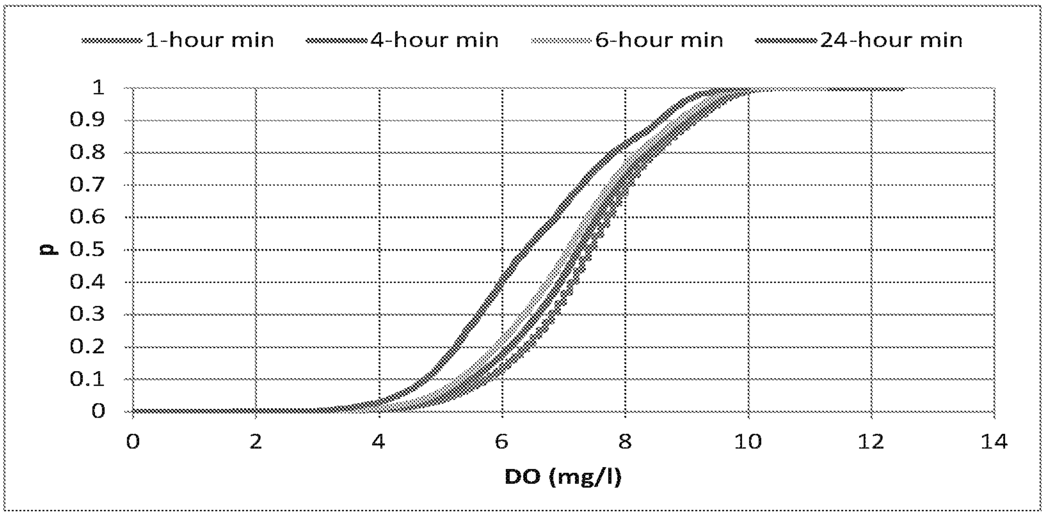

Figure B-42 Cumulative probability (p) distributions of 1-hour min, 4-hour min, 6-hour min, and 24-hour minimum DO concentrations at Second Mallard Slough

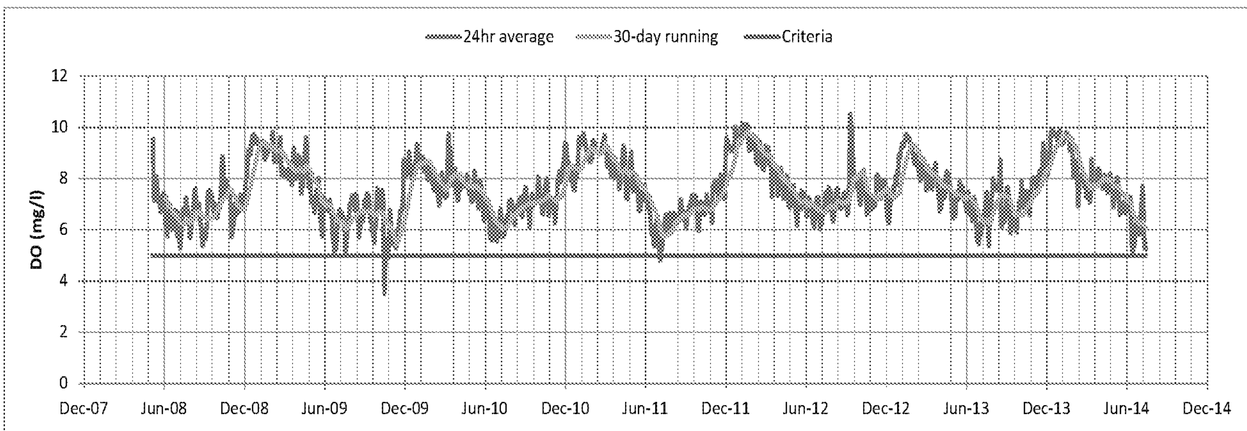

Figure B-43 24-hour running average and 30-day running average DO at Second Mallard Slough compared to a target of % mg/L

Table B-7 Evaluation of different time periods for continuous DO data collected at First and Second Mallard Sloughs

	1 hour	4 hour	6 hour	24 hour
Second Mallard				
Min	0.3	0.3	0.3	0.3
Max	12.5	11.4	10.8	9.9
Mean	7.4	7.0	6.8	6.2
Standard Deviation	1.3	1.4	1.4	1.5
95th percentile	9.5	9.2	9.1	8.7
5th percentile	5.2	4.8	4.6	3.9
First Mallard				
Min	0.0	0.0	0.0	1.5
Max	11.3	10.4	9.2	10.0
Mean	6.5	6.4	5.9	6.9
Standard Deviation	1.3	1.3	1.4	1.1
95th percentile	8.6	8.4	8.1	8.8
5th percentile	4.3	4.1	3.4	5.1

Explanation:
1 hour estimates represent min, max and mean values based on 4 DO readings in each hour
4 hour estimates - data were averaged first on hourly basis, and then min, max and mean values were estimated

Appendix B References

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APPENDIX C: DO MODELING WITH HEC-RAS

Prepared by Tetra Tech Inc., 2013

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DO Modeling with HEC-RAS

Prepared by Tetra Tech Inc., 2013

A numeric hydraulic model (HEC-RAS; USACE 2010) was used to simulate linkages between organic carbon loads from managed wetlands and dissolved oxygen in the Suisun Marsh sloughs. The model was run for two sloughs that experienced frequent low DO concentrations, Boynton and Peytonia Sloughs, which were continuously monitored by Siegel et al. (2011) during 2007–2008, and two other sloughs, Goodyear and Denverton Sloughs, which were recently monitored by the Regional Water Board from 2012–2013 (Figure C-1 through Figure C-3).

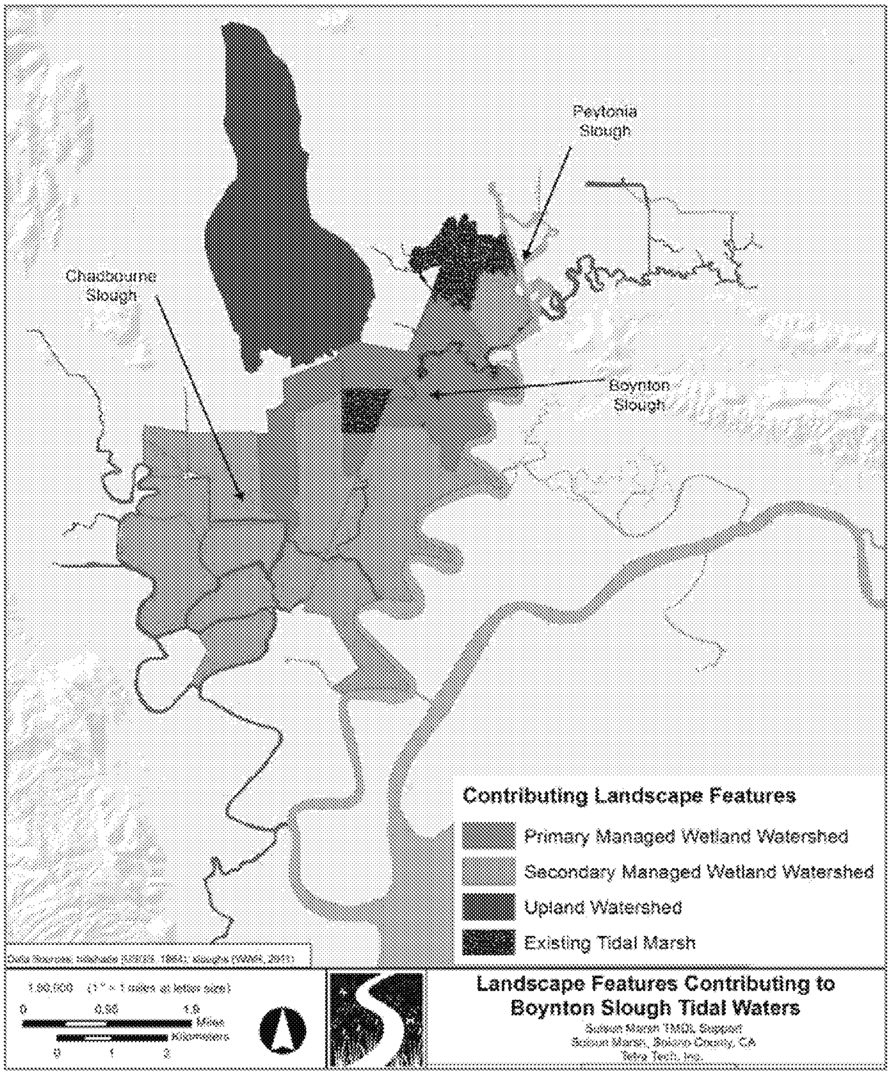

Figure C-1 Locations of Boynton and Peytonia Sloughs with surrounding wetlands and upland watershed

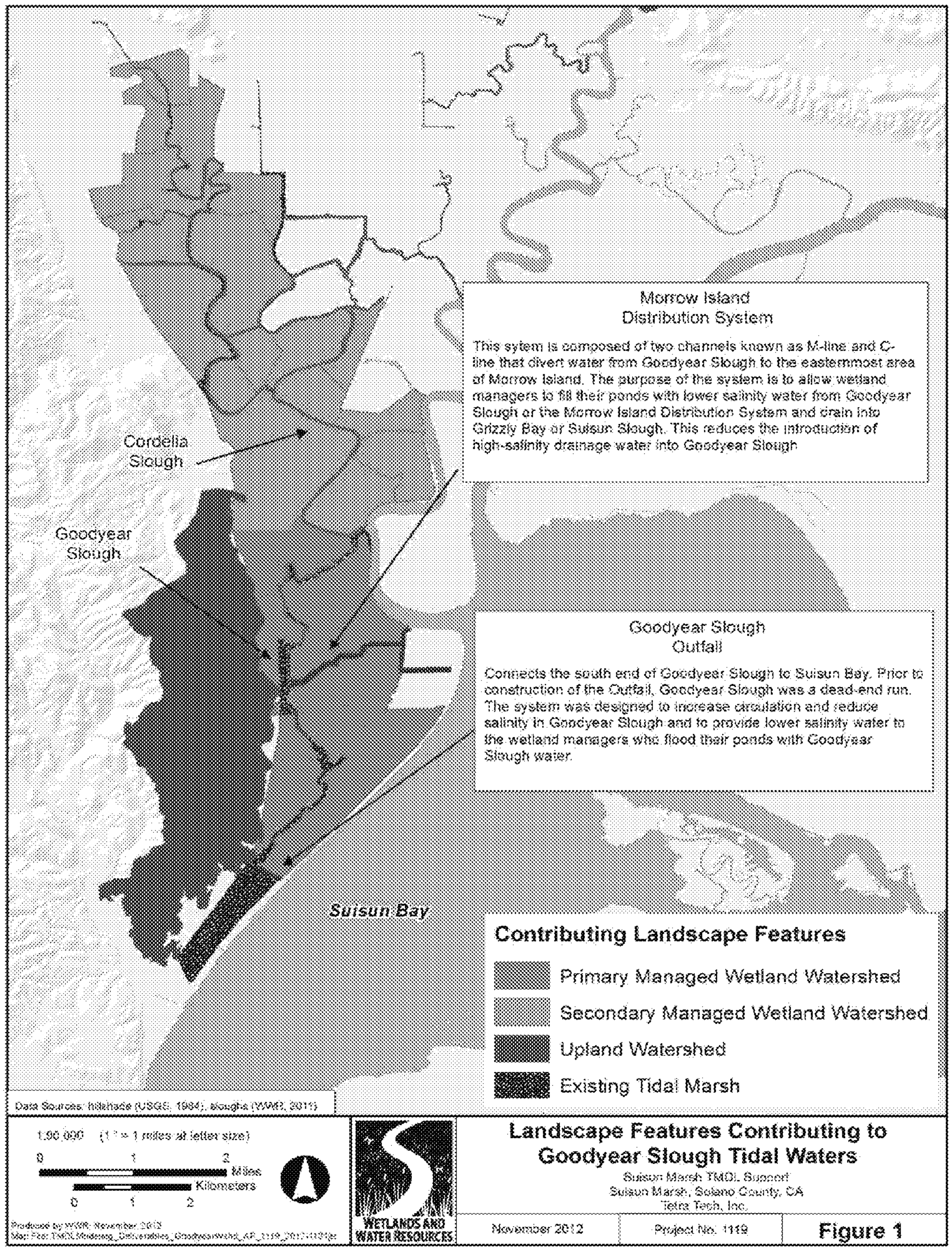

Figure C-2 Locations of Goodyear Slough with surrounding wetlands and upland watershed

Simulated Sloughs

Both, Boynton and Peytonia Sloughs had experienced periods of low DO in the past. These sloughs receive discharges from managed wetlands. Peytonia Slough is connected to Wetland 112, 113, 123 and 211 (Figure C-4 and Figure C-12). Boynton Slough is bounded by Wetland 211 at its confluence with Suisun Slough and Wetland 123 and 124, and connected to Wetland 133, 122, 130, and 131. In addition to the managed wetland discharges, Boynton Slough receives discharges from the FSSD wastewater treatment plant (Figure C-4). On average, Boynton Slough receives 90% of FSSD discharge and Peytonia Slough receives 10% of the FSSD discharge. Both sloughs are connected to

Wetland 123. It was documented that under normal conditions, Wetland 123 will draw water from Peytonia Slough and drain to Boynton Slough (Siegel et al. 2011). The comparison of Boynton and Peytonia Slough and their surrounding wetlands is shown in Table A-4 (Attachment).

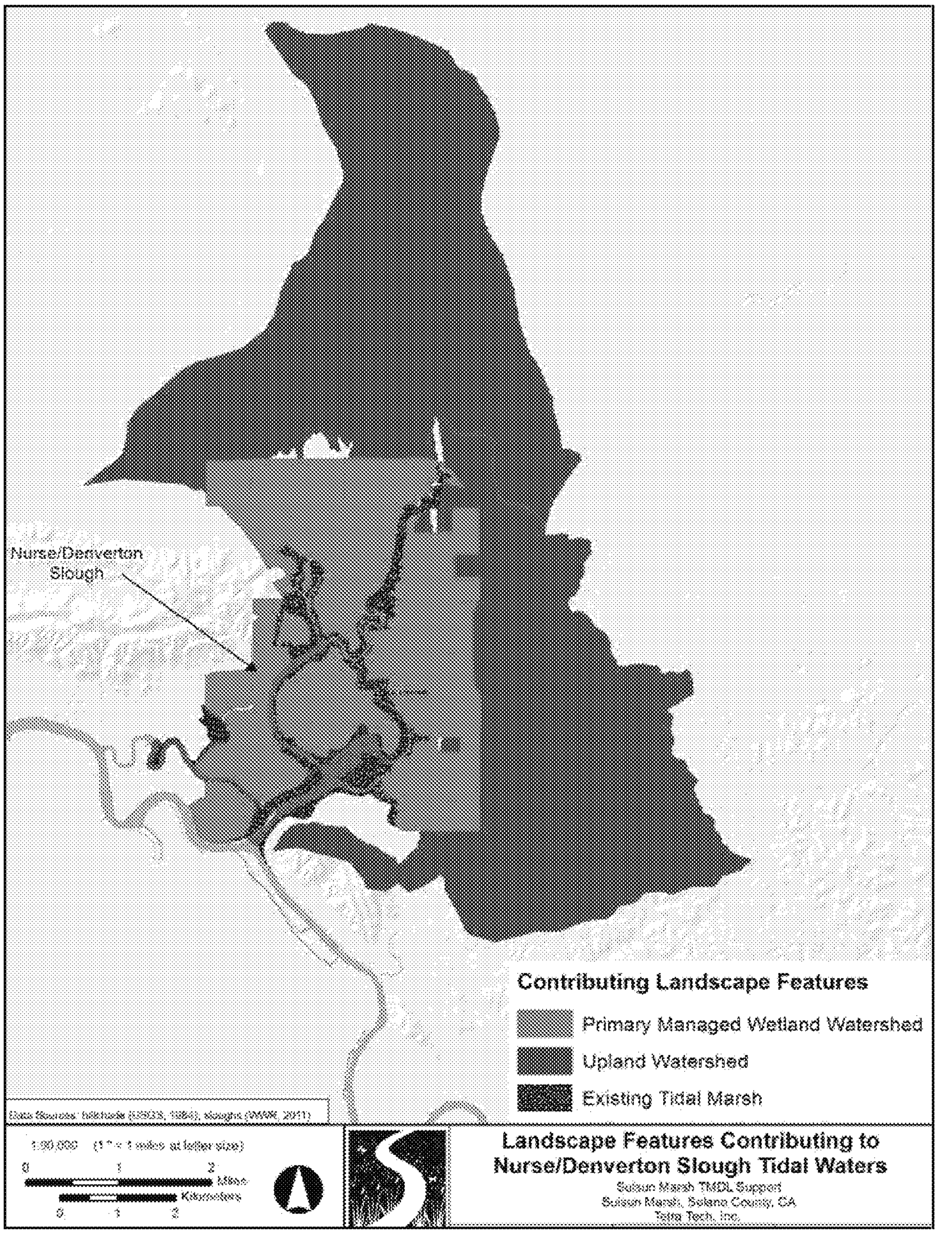

Figure C-3 Locations of Denverton Slough with surrounding wetlands and upland watershed

Goodyear and Denverton Sloughs are located in the southwest and northeast of Suisun Marsh. Similar to Boynton and Peytonia Sloughs, Goodyear Slough received discharges from managed wetland and has experienced frequent low DO events and fish kills in the past. Goodyear Slough watershed is also characterized by dead-end narrow slough channels. The mixing and reaeration in a narrow slough are considered to be limited. Denverton Slough, located in the northwest of Suisun Marsh, has wider channels and is considered to have higher DO concentrations. DO concentrations in Denverton Slough, although higher than Goodyear Slough, still showed frequent depressions under 5 mg/L possibly due to managed wetland discharges. In the following sections we describe the model application to Boynton, Peytonia, Goodyear, and Denverton Sloughs.

Model Simulations in Boynton Slough

HEC-RAS Model Set Up

The sloughs in Suisun Marsh are subject to tidal influence. The tidal energy that enters the sloughs can propagate upstream and dissipates when it reaches the upper slough. As a result, reaeration in the sloughs due to tidal mixing could be enhanced. In order to simulate mixing of tidal flow and slough water, the HEC-RAS model was run for a typical discharge period (09/27/2008–09/30/2008), using flow and stage data observed near the mouth (Siegel et al. 2011) as an input.

Boynton Slough receives discharges from FSSD and managed wetlands (Wetland 123). There are four flood and external water management structures on Boynton Slough, located roughly at 0.3, 1.3, 2.2, and 3.1 kilometers from the mouth (showed as purple arrow in Figure C-4). The discharge from FSSD (blue arrow) is located at roughly 2.8 km from the mouth of the slough.

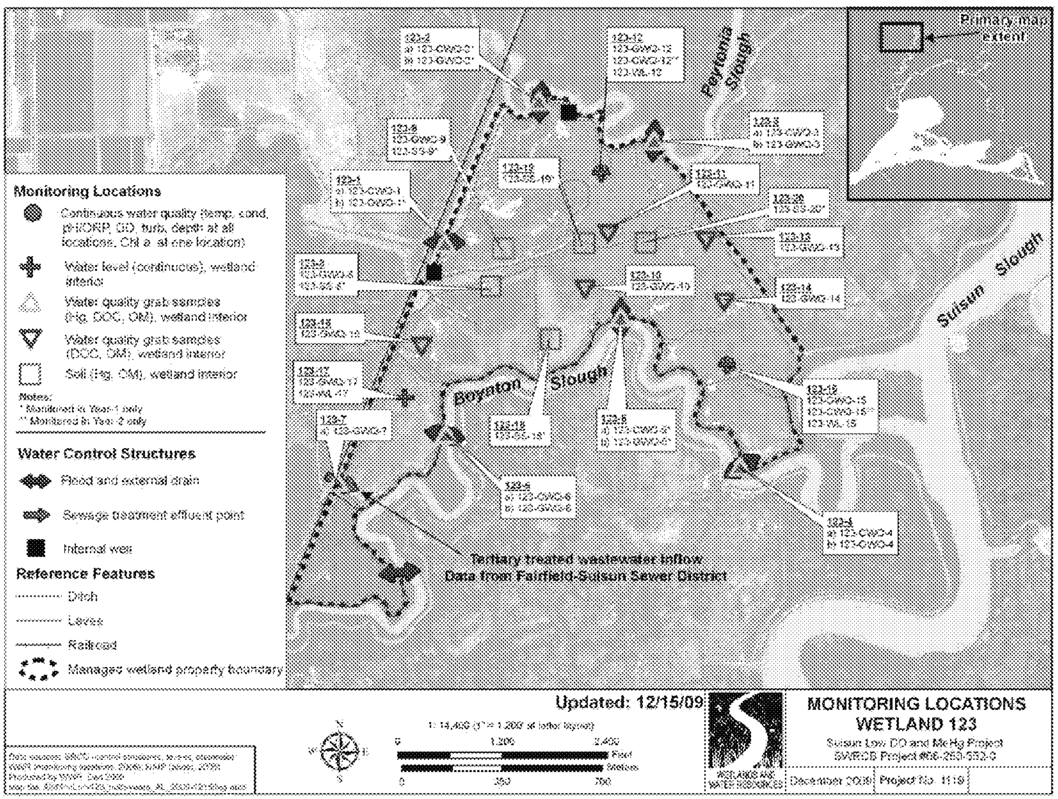

Figure C-4 Locations of FSSD and managed wetland discharges in Boynton Slough

For the HEC-RAS modeling, Boynton Slough is represented by a main reach (Reach 2) and two upstream tributaries (R1, and R1a) (Figure C-5). The slough was modeled by assuming a headwater flow of 5 cfs from the upland tributaries. The amount of discharge from FSSD (Table A-1 in the Attachment) and water management data for Wetland 123 were reported in an earlier study (Siegel et al. 2011). The major discharge events from wetlands 123 and 112 summarized in Table A-2 and Table A-3, and the observed concentrations of dissolved oxygen, organic carbon and chlorophyll a from perimeter sites of the managed wetlands were used in the modeling (Figure A-1and Figure A- 2 in the Attachment). Some smaller discharge events, which resulted in noticeable DO sags in the sloughs, were also included in the model setup. The resulting schedule of discharge events is shown in Figure A-3 (Attachment). The volume of discharge at each discharge location (a total of four) was assumed to be the same at 1/4th of the total discharge monitored during the period of 2007–2008 by Siegel et al. (2011). The discharge from FSSD was modeled as a point source, using the monthly monitoring data. The observed flow and stage data at the mouth of Boynton Slough were used as the downstream boundary conditions of the model (Figure C-6). Based on the available data, Boynton Slough was modeled for the period of 09/15/2007 – 03/14/2008.

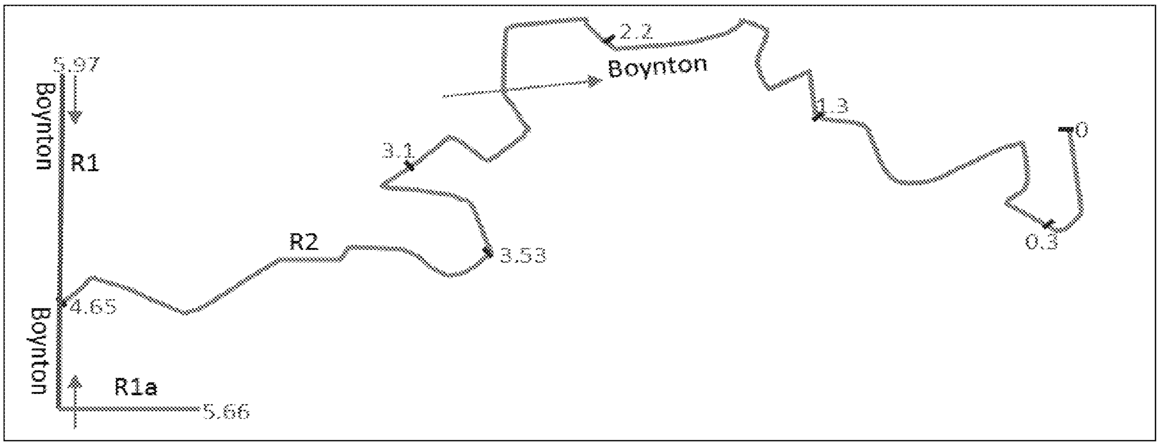

Figure C-5 Schematic representation of Boynton Slough in HEC-RAS model with distance (in km) from mouth and reaches (R1, R1a, and R2) shown

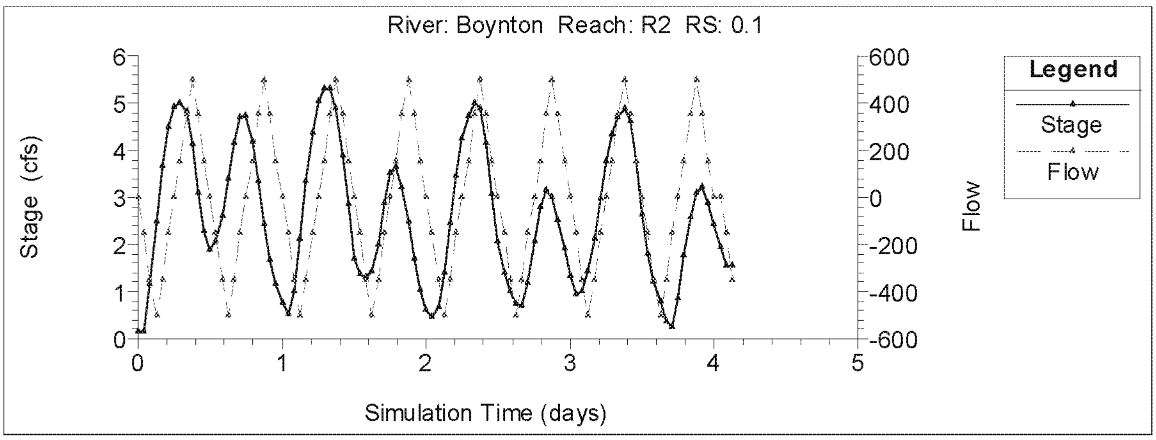

Figure C-6 Flow–stage relationship at boundary location of Boynton Slough

Model Results: Boynton Slough

The simulated flow, stage, and velocity at an hourly time step at different locations of Boynton Slough are shown in Figure C-7 and Figure C-8. The flow at the mouth of the slough changes between -400 to 400 cfs within a tidal cycle, and the magnitude of flow variation during a tidal cycle decreases upstream. The simulated tidal stage at the mouth of the slough varied from 0.3 to 5.3 ft within the tidal cycles. The tidal velocity at the mouth of the slough varied from -1.2 ft/s to 2.2 ft/s (Figure C-9). The model simulated tidal velocity agrees with a measured tidal velocity of 1 cfs. The simulated tidal stage and velocity decreases upstream, due to dissipation of tidal energy.

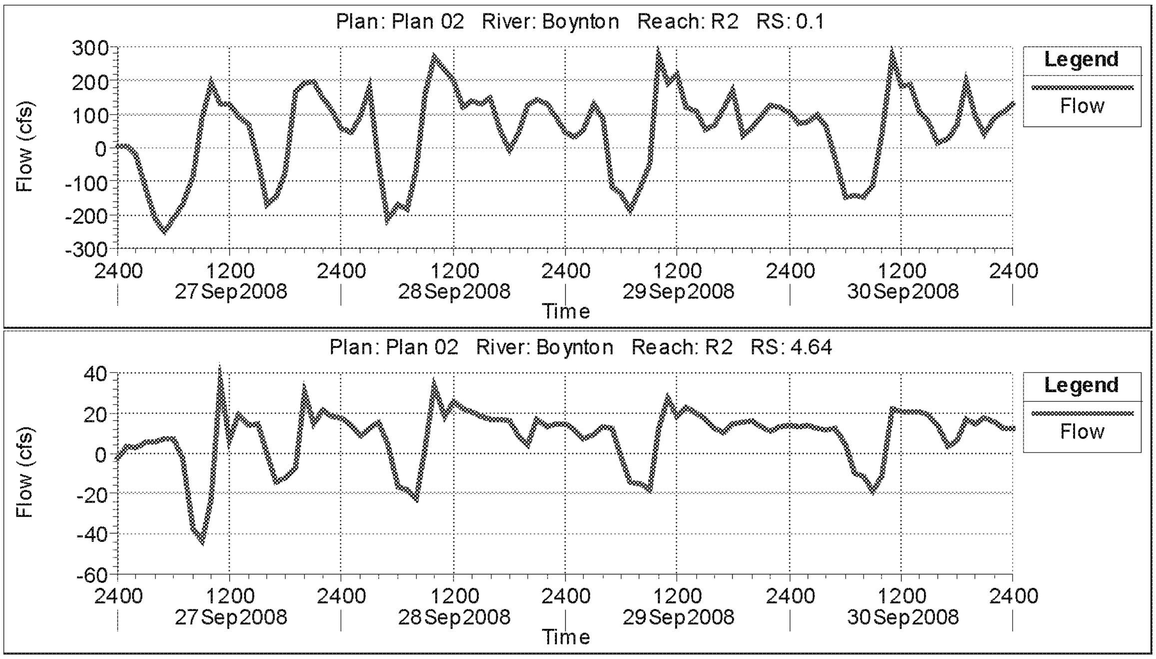

Figure C-7 Simulated variations in flow near the mouth of Boynton Slough (R2, 0.1 km from mouth) and upstream reach (R1a, 4.64 km from mouth) by HEC-RAS

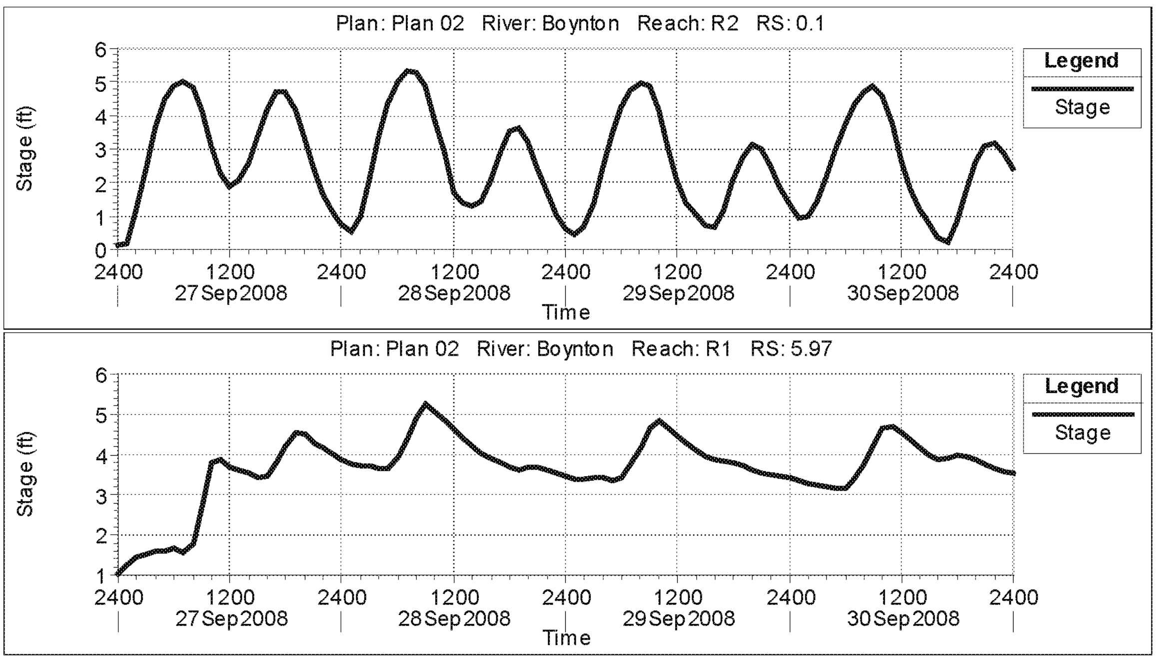

Figure C-8 Simulated variations in stage near the mouth of Boynton Slough (R2, 0.1 km from mouth) and upstream reach (R1a, 5.97km from mouth) by HEC-RAS

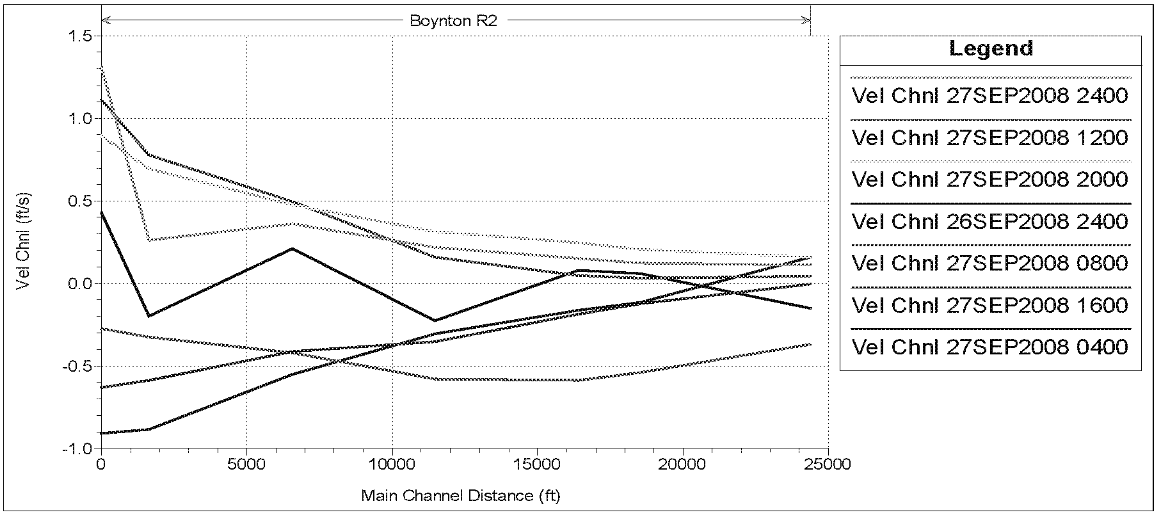

Figure C-9 Simulated velocity every four hours for a period of 24 hours in Boynton Slough from mouth to head by HEC-RAS

The model-simulated temperature and DO at 15-minute intervals were compared to the observed data for Boynton Slough (Figure C-10, Figure C-11). The measured temperature decreases from September to January and then increases from January to March. The model is able to capture this pattern in observed temperature. Boynton Slough receives significant discharges from managed wetlands during October and November, as indicated by frequent declines in observed DO. The model was able to capture these DO sags (October–November) and showed the increasing DO concentrations (December–February) that matched the observed data reasonably well.

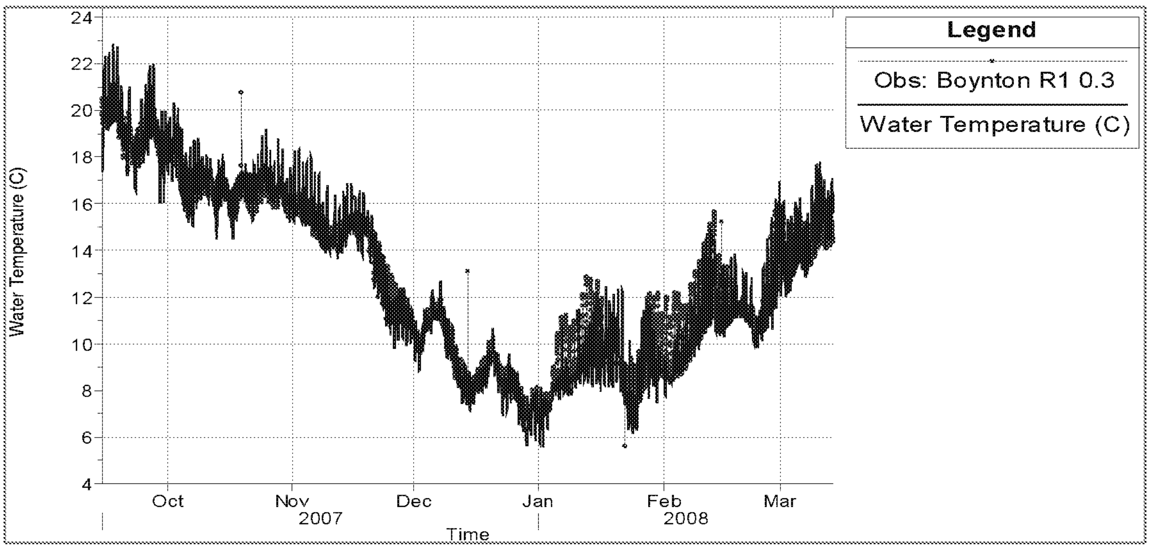

Figure C-10 Model simulated water temperature in Boynton Slough compared to 15-minute interval data

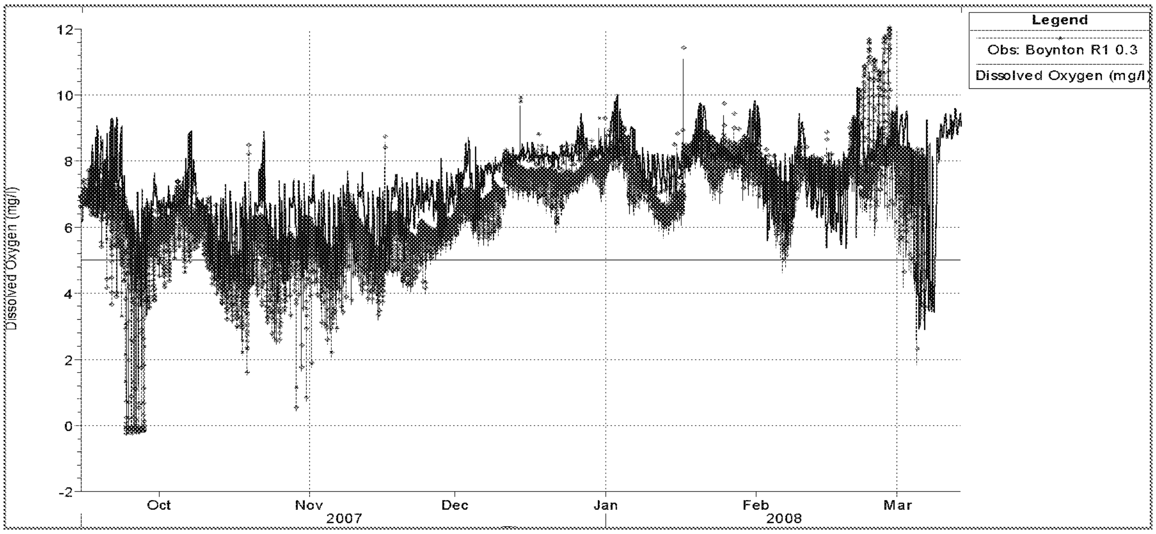

Figure C-11 Model simulated DO concentrations in Boynton Slough compared to observed data at 15-minute intervals

Model Simulations in Peytonia Slough

HEC-RAS Model Set Up

Peytonia Slough has a total length of 2.5 miles. Peytonia Slough receives 10% of the total FSSD discharge on average, and the discharge from only one managed wetland (Wetland 112). Therefore, it was assumed that all drainage from Wetland 112 drains to this slough measured at Station 112-1 located approximately 2.5 km from the mouth of the slough. Figure C-12 shows the points of discharge for FSSD (purple arrow) and Wetland 112 (blue arrow). Peytonia Slough also receives watershed inputs from Ledgewood Creek, which has 13,000 acres of drainage area. Inputs from the surrounding watersheds to the slough were specified based on a modeling study by Davis et al. (2000b), proportional to the drainage area. The location of continuous DO monitoring in Peytonia Slough is shown in Figure C-12.

For the HEC-RAS modeling, Peytonia Slough is represented by a single reach (R3, Figure C-13). The slough was modeled using a headwater flow of 8 cfs estimated from the surrounding upland watersheds. The discharge from managed wetlands was specified at the middle of the slough at approximately 2.5 km from the mouth. The discharge from FSSD was specified as point source at 1/10th of the FSSD discharge monitored by Siegel et al. (2011). The observed flow and stage data at the mouth of Peytonia Slough were assigned as the downstream boundary conditions (Figure C-14). Peytonia Slough was monitored for the period of 09/14/2007 – 03/14/2008.

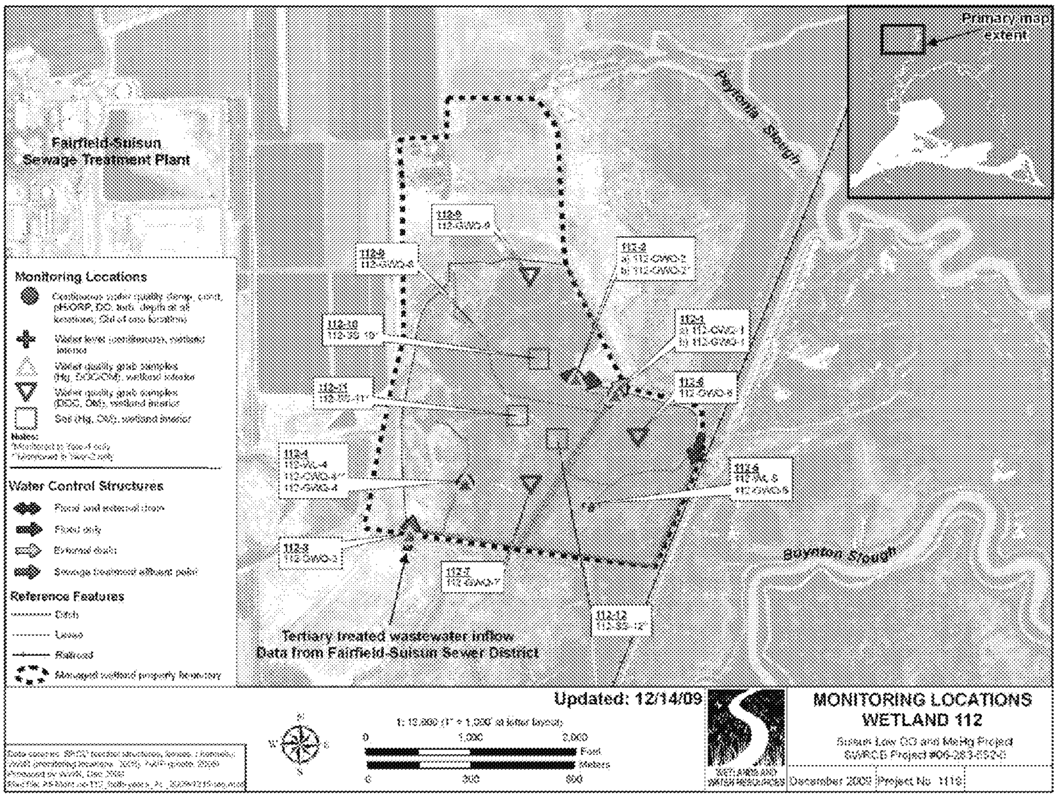

Figure C-12 Locations of sewage effluent inflow and managed wetland discharge for Peytonia Slough (Siegel et al. 2011)

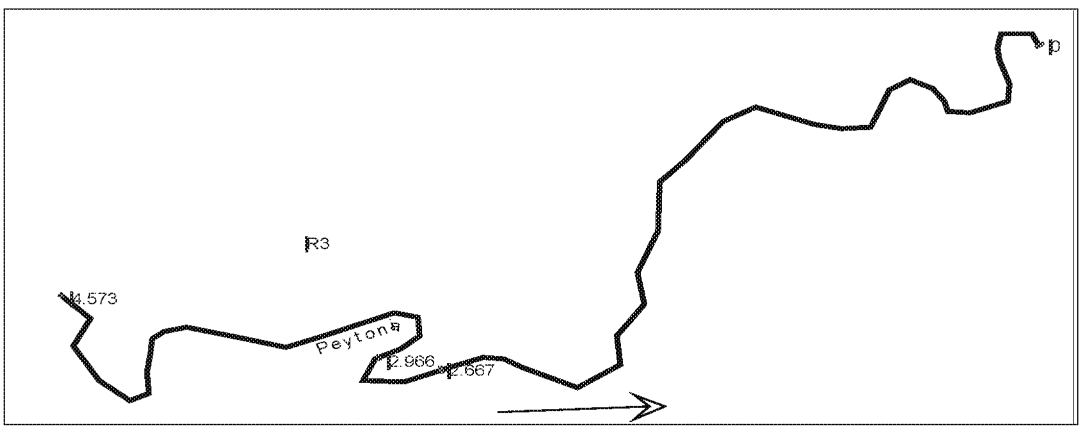

Figure C-13 Geometric data of Peytonia Slough in HEC-RAS model with river miles (in km from mouth) and reach (R3) shown

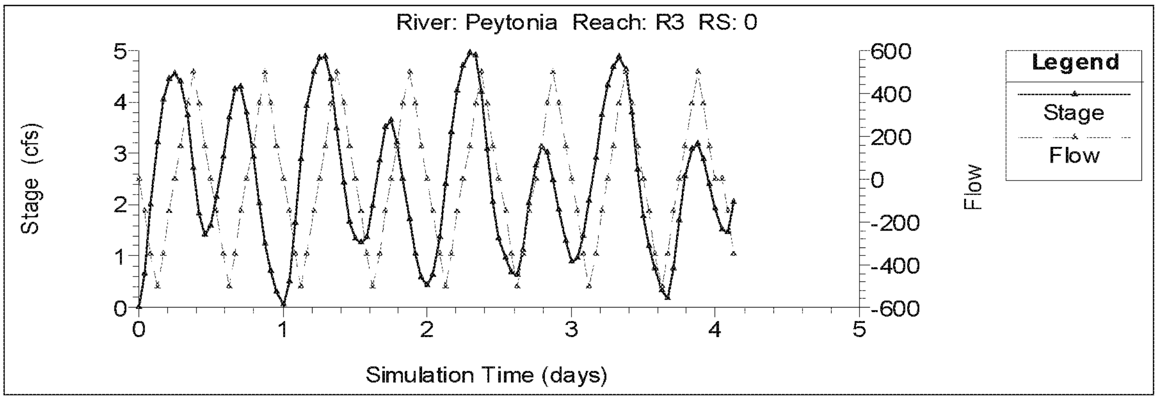

Figure C-14 Flow – stage relationship at the downstream boundary location of Peytonia Slough

Model Results: Peytonia Slough

The simulated flow, stage, and velocity at an hourly time step at different locations of Peytonia Slough are shown in Figure C-15 to Figure C-17. The flow at the mouth of the slough ranges between -300 to 300 cfs within a tidal cycle, and the magnitude of flow variation during a tidal cycle decreases upstream. The simulated tidal stage at the mouth of the slough varied from 0 to 5 ft within the tidal cycles while the tidal velocity at the mouth of the slough varied from -1 ft/s to 1 ft/s. The model-simulated tidal velocity agrees with the measured tidal velocity of 1 cfs. The simulated tidal stage and velocity decreases upstream, due to dissipation of tidal energy.

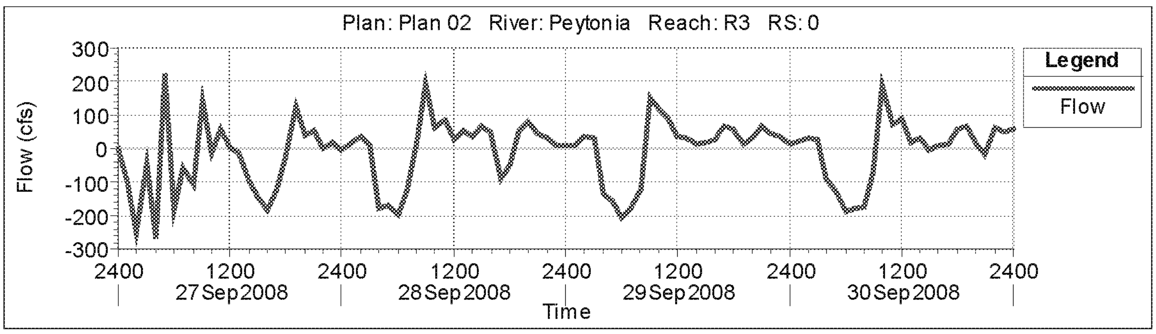

Figure C-15 Simulated variations in flow near the mouth of Peytonia Slough (R3, 0.0 km from mouth) by HEC-RAS

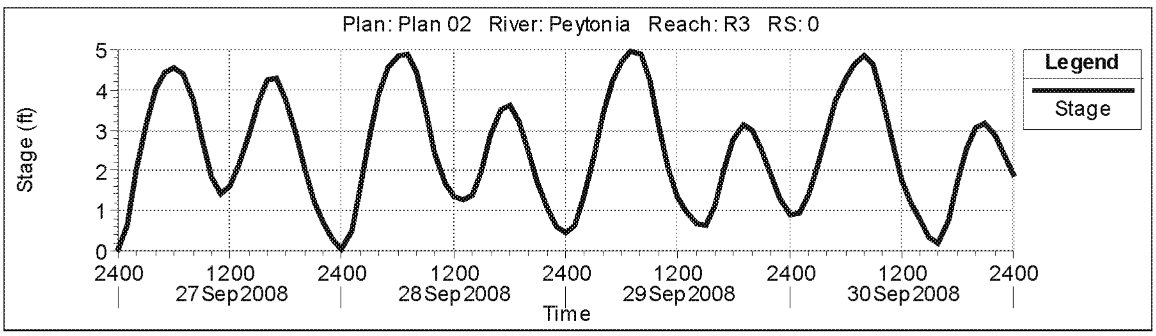

Figure C-16 Simulated variations in stage near the mouth of Peytonia Slough (R3, 0.0 km from mouth) by HEC-RAS

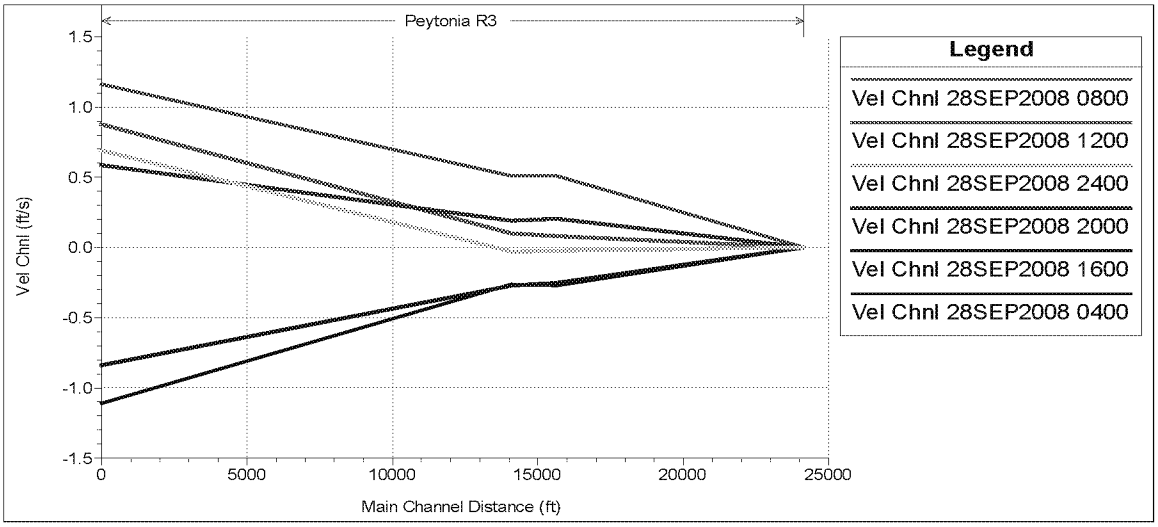

Figure C-17 Simulated velocity at every four hour for a period of 24 hours in Peytonia Slough from mouth to head by HEC-RAS

The model-simulated temperature and DO at 15 minute intervals were compared to the observed data for Peytonia Slough (Figure C-18 and Figure C-19). The observed temperature generally showed a decreasing trend from September to January, and then increasing trend from January to March. The model is able to capture this pattern in observed temperature. Peytonia Slough receives significant discharges during the months of October to December, as indicated by frequent declines in observed DO. Overall, the model is able to capture the low DO for most of the discharge events. However, the model does not represent well the significant diurnal changes in DO, which were frequently observed in Peytonia Slough during October-November 2007.

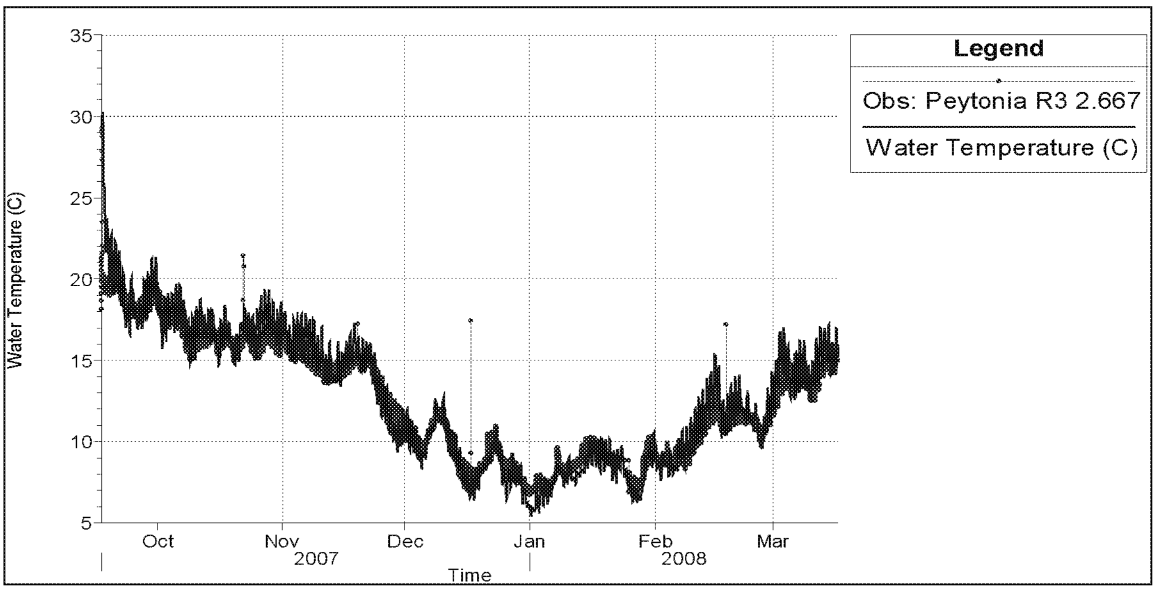

Figure C-18 Model simulated water temperature in Peytonia Slough compared to 15-minute interval data

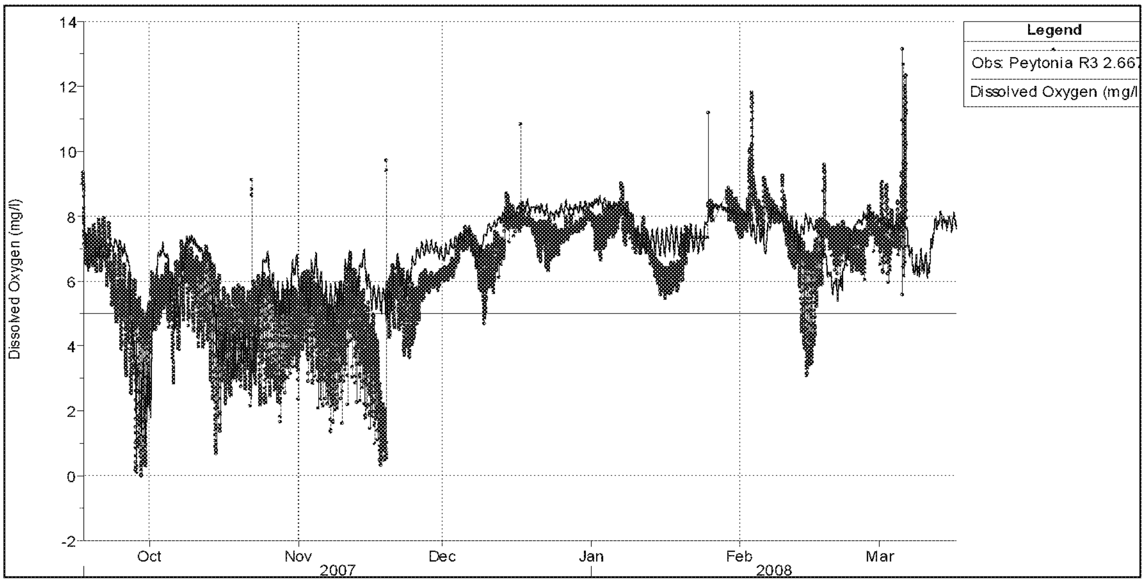

Figure C-19 Model simulated DO concentrations in Peytonia Slough compared to observed data at 15 minute intervals

Model Simulations in Goodyear and Denverton Slough

Goodyear and Denverton Sloughs also receive discharges from managed wetlands and experience low DO events. Goodyear Slough has been known to have reoccurring low DO conditions every fall and most severe and frequent fish kills. The magnitude of low DO events in Goodyear Slough is similar to those in Boynton and Peytonia Slough. Denverton Slough, on the other hand, shows better DO conditions. The Regional Water Board conducted continuous measurements of DO and temperature at 15-minute intervals from 2012–2013 in Goodyear and Denverton Sloughs.

HEC-RAS Model Set Up

The model set up for Goodyear and Denverton Sloughs followed the same approach as used for Boynton and Peytonia Sloughs. The geometry data (length and width) of the sloughs was obtained from Wetlands and Water Resources. The same meteorology data as used in Boynton and Peytonia Slough were also employed in Goodyear and Denverton Sloughs. The DSM2 simulated flow and stage at mouth of each slough was used as boundary inputs to the model. For these two sloughs, the wetland discharge information is lacking. Instead the discharges were estimated in the modeling by assuming several large discharge events to the sloughs, at a magnitude similar to those in Boynton and Peytonia Sloughs during the time when low DO concentrations were observed. The schedule and magnitude of the discharge events are shown in Figure A-5 and Figure A-6 (in the Attachment). The managed wetland discharges were conservatively assumed to have the same concentrations as those observed in managed wetlands discharging to Boynton and Peytonia Slough (Wetland 112 and 123) despite the fact that wetlands draining to Denverton Slough are known to be managed less intensively. Based on the available DO data for comparison, Goodyear Slough was modeled for the period of 08/24/2012 – 01/25/2013 and Denverton Slough was modeled for the period of 08/15/2012 – 02/01/2013.

Model Results: Goodyear and Denverton Slough

The model-simulated temperature and DO at 15 minute intervals were compared to the observed data for Goodyear Slough (Figure C-20 and Figure C-21). The temperature generally showed a decreasing trend from September 2012 to January 2013, and then increased from January 2013. The model is able to capture this pattern in observed temperature well. As a result, dissolved oxygen concentrations were higher from October to January. Goodyear Slough receives significant discharges from managed wetlands during October to December, as indicated by frequent declines in the observed DO. Goodyear Slough received four major discharges in October–December 2012 and one noticeable discharge in January 2013. Overall, the model is able to capture the low DO observed for most of the discharge events. Simulations for Denverton Slough again showed good agreement between water temperature and DO with the observed data (Figure C-22 and Figure C-23). However, the magnitude of diurnal variations in DO simulated by the model is much smaller than the variations observed in both sloughs.

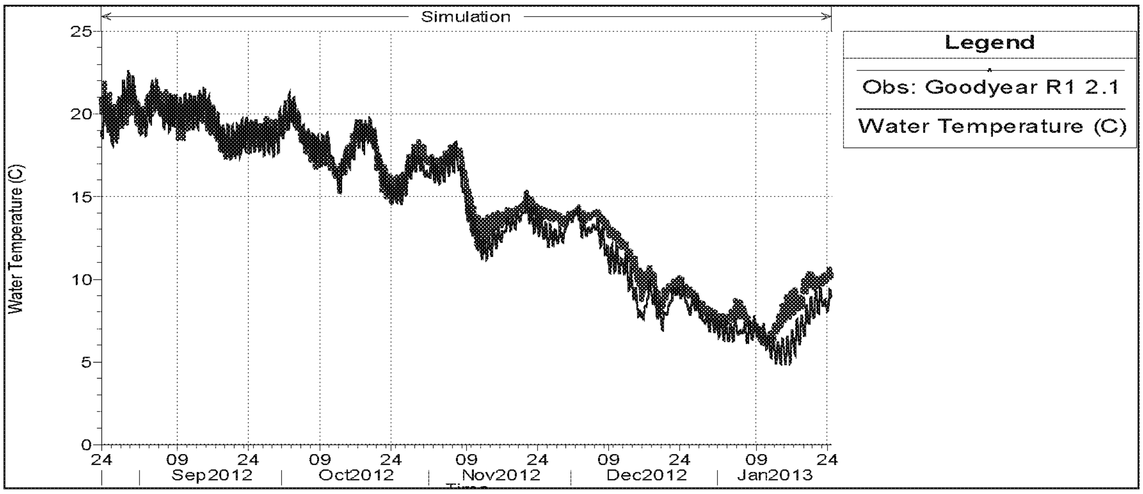

Figure C-20 Model-simulated water temperature in Goodyear Slough compared to observed data at 15-minute intervals

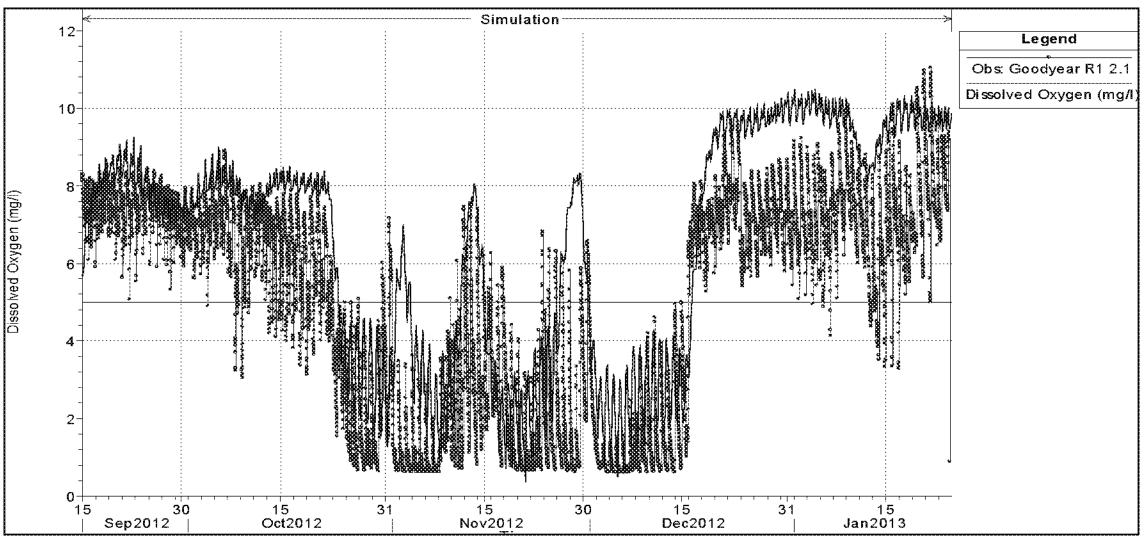

Figure C-21 Model-simulated DO concentrations in Goodyear Slough compared to observed data at 15-minute intervals

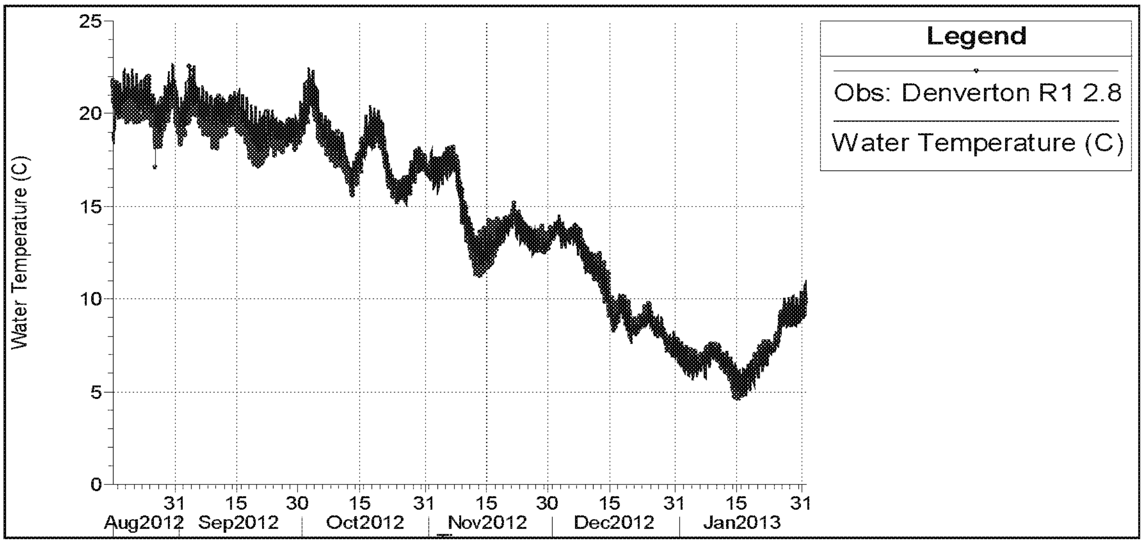

Figure C-22 Model-simulated water temperature in Denverton Slough compared to observed data at 15-minute intervals

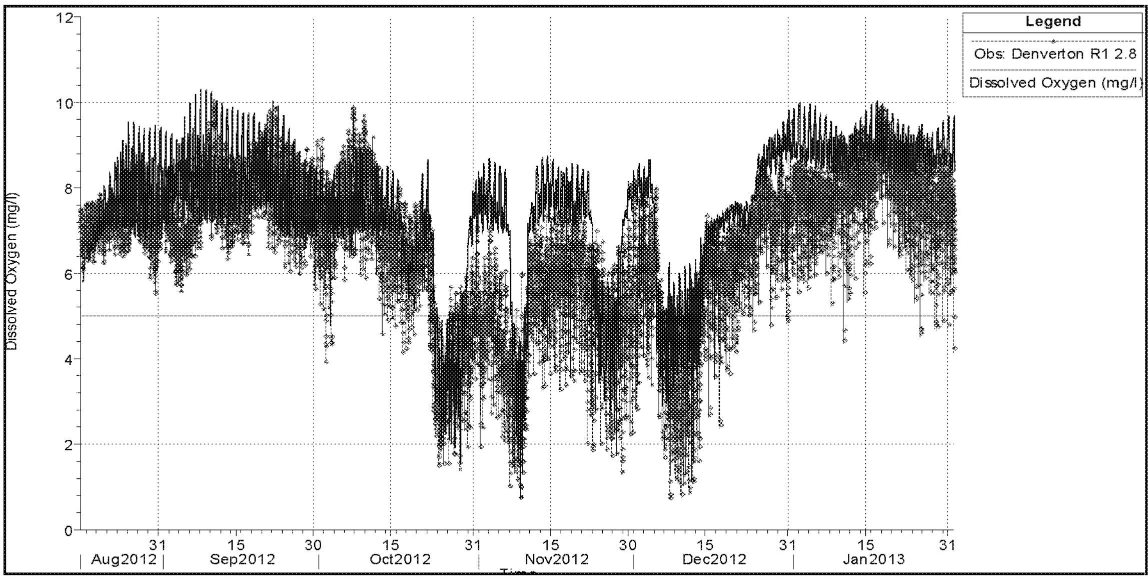

Figure C-23 Model-simulated DO concentrations in Denverton Slough compared to observed data at 15-minute intervals

Scenario Testing to Increase DO in Receiving Sloughs

The ability of Boynton, Peytonia, Goodyear, and Denverton Sloughs to maintain DO above 5 mg/L under continuous exposure was tested using the calibrated HEC-RES model. This DO level was assumed to protect fish from undesirable growth effects under the continuous exposure. A lower DO level of 3.3 mg/L, protective of juvenile and adult survival under the continuous exposure, was also tested. When the exposure is less than 24 hours, DO concentrations are allowed to go below 5 mg/L for short amount of time, as long as the cumulative growth effect is less than 25% (EPA, 2000). This suggests that DO at a specific site does not have to be above 5 mg/L for 100% of the time. Instead for episodic exposure of less than 24 hours, DO concentrations can go below 5 mg/L, as long as the cumulative growth effects from that event are less than 25%. The allowable exposure duration at DO lower than continuous exposure limit, such as 5 mg/L can be estimated using the functions established by EPA (2000). Details for deriving these site specific DO thresholds for Suisun Marsh are documented elsewhere (Tetra Tech, 2014). For this assessment, it was assumed that the simulated DO needs to be above 5 mg/L for exposures over 24 hours, with some occasional exposure allowed as long as the episodic exposure does not result in cumulative growth effects exceeding 25%.

Two model scenarios were tested to achieve the DO targets as defined above.

Model Scenario 1 estimated the managed wetland discharge volume reduction necessary to meet the continuous exposure DO target of 5 mg/L in the sloughs.

Model Scenario 2 tested the effect of discharging the total load without any reductions over a longer period, and the maximum allowable continuous daily discharge from managed wetlands that would result in attaining a continuous exposure DO target of 5 mg/L.

Boynton Slough

Under Model Scenario 1, discharges from managed wetlands to Boynton Slough need to be reduced by approximately 40% from the current rates of 19 to 41 cfs and existing schedule (Figure A-3, Table A-2, in the Attachment) during the period of 09/07 – 03/08 to achieve the DO concentration of 5 mg/L. At this level of load reduction, minimum DO concentrations are generally above 5 mg/L (Figure C-24). There was some occasional exposure to low DO of 5 mg/L, however, the exposure was generally less than 8 hours (allowable duration at 4 mg/L for growth effect impacts of < 25%). The level of reduction depends on discharge volume and observed concentrations from managed wetland 123 (i.e., organic carbon concentrations of 18 – 70 mg/L at different discharge locations, as shown in Figure C-4; DO near 0 mg/L).

Model Scenario 2 tested the feasibility of discharging the loads over a longer period without reductions in total load. The results suggested that with a continuous discharge (at 2.55 cfs, without changes in total load), DO concentrations were mostly above the target of 5 mg/L (Figure C-25). The allowable discharge is a 2.55 cfs on daily basis for the entire simulation period.

The model also tested a future scenario of 50% increase in the FSSD discharge with other discharges at baseline conditions. The results indicate a slight increase in DO in the channel due to increases in this discharge (Figure C-26). Discharges from FSSD are shown to benefit DO concentrations in sloughs in Suisun Marsh, due to higher DO and low organic carbon concentrations, in comparison to the managed wetland concentrations.

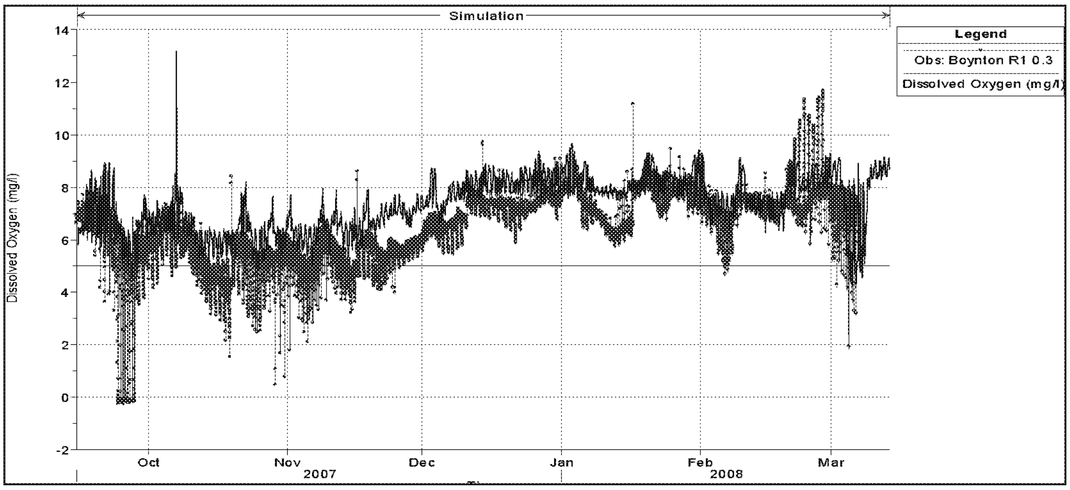

Figure C-24 Model-simulated DO concentrations in Boynton Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

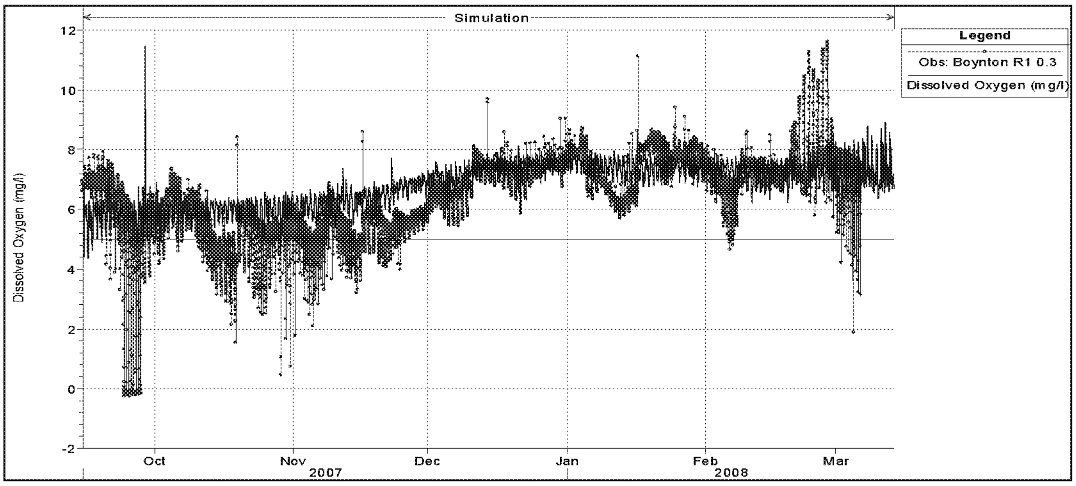

Figure C-25 Model-simulated DO concentrations in Boynton Slough with continuous low discharge to achieve 5 mg/L DO (Model Scenario 2)

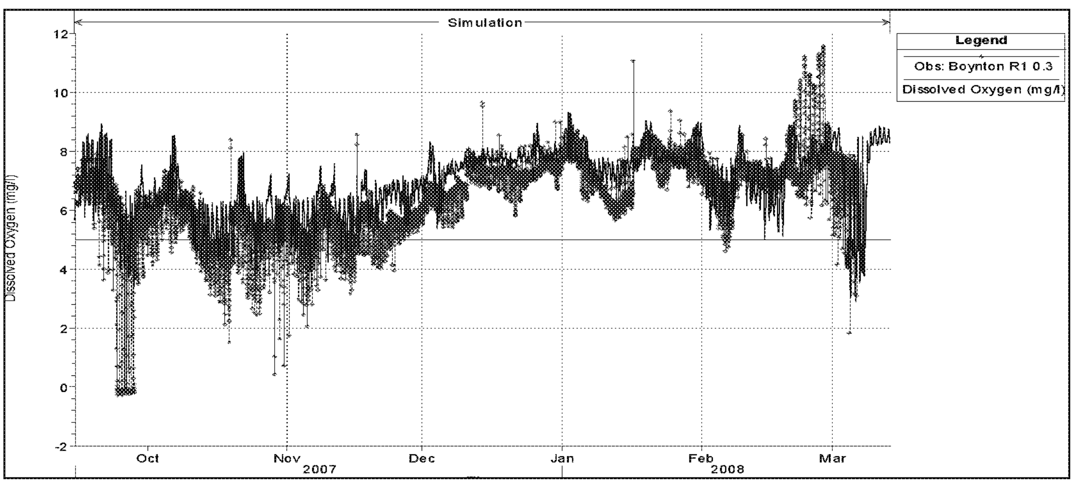

Figure C-26 Model-simulated DO concentrations in Boynton Slough as a result of 50% increase in FSSD discharge

Peytonia Slough

Discharges from managed wetlands to Peytonia Slough were simulated in a similar manner to Boynton Slough. Model Scenario 1 estimated the load reduction required in managed wetland discharges to achieve the DO target. The results indicate that a 65% reduction of wetland discharge from the current rate (maximum of 16 cfs observed, see Attachment: (Table A-3) and schedule (Figure A-4) will result in minimum DO greater than 5 mg/L (Figure C-27). The estimated allowable discharge under this scenario is 5.6 cfs at current concentrations of 70 mg/L DOC and 0.7 mg/L DO (Figure A-1and Figure A- 2 in the Attachment). The simulated DO is mostly above 5 mg/L, with one incidence of exposure to DO lower than 5 mg/L. The exposure to low DO is for short amount of time (< 8 hours with DO > 4 mg/L). The modeled scenario assumes discharge events ranging from 10 to 16 cfs (Figure A-4, Figure A-3 in the Attachment). All of these discharge events need to be reduced by more than 60%, for approximately 85 days out of the 207 modeled days.

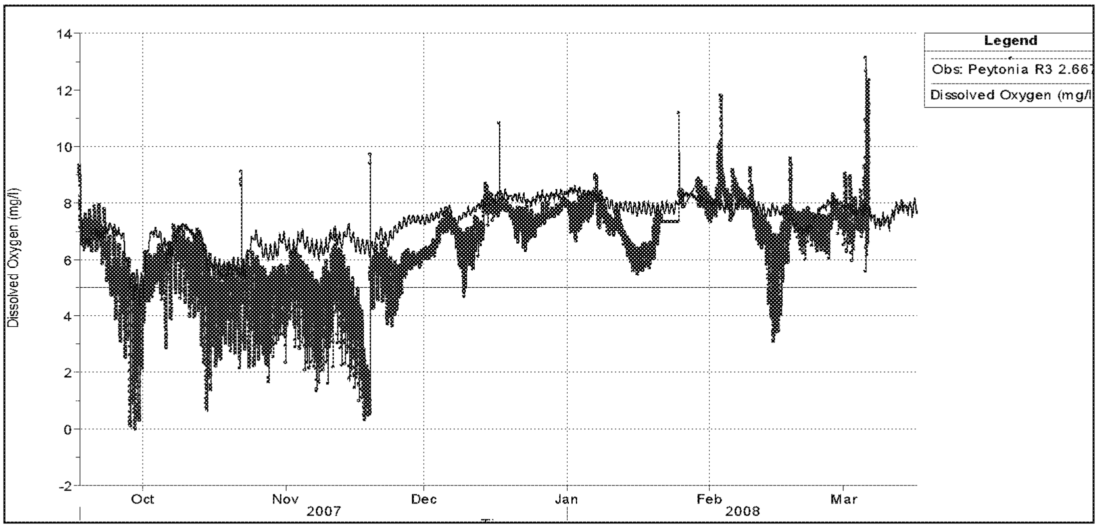

Figure C-27 Model-simulated DO concentrations in Peytonia Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

Model Scenario 2 tested the possibility of discharging loads over a longer time period without reductions in total load. The results suggested that with a continuous low discharge, DO concentrations were above 5 mg/L for the simulation period (Figure C-28). To achieve the DO target, the allowed continuous daily discharge from managed wetlands is 4 cfs at current concentrations from managed wetlands (i.e., 70 mg/L DOC, 0.7 mg/L DO) for the entire simulation period. This situation is different from that of Boynton Slough, where the continuous flow alone could not achieve the 5 mg/L target, and had to be coupled with a flow reduction.

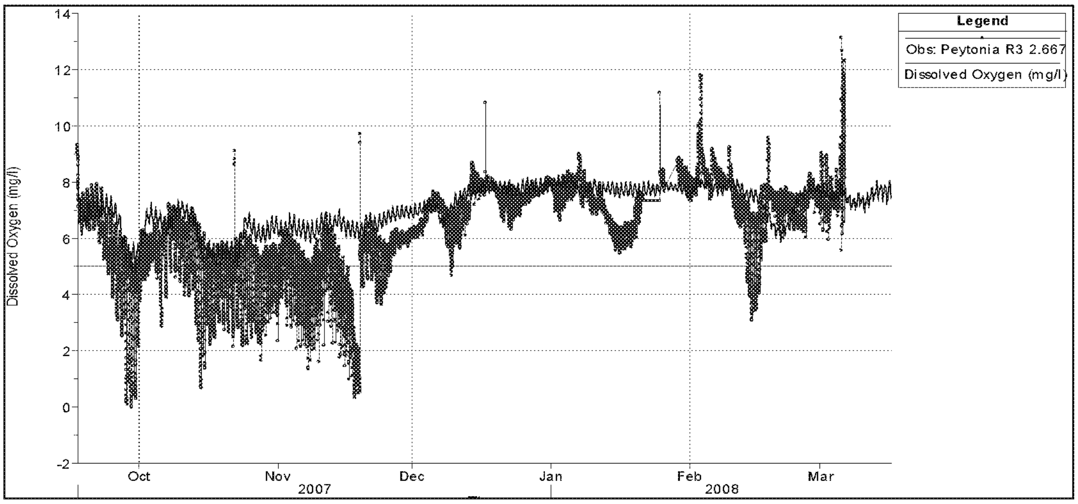

Figure C-28 Model-simulated DO concentrations in Peytonia Slough with continuous flow discharge without load reduction to achieve 5 mg/L DO (Model Scenario 2)

Goodyear Slough

For Goodyear Slough Model Scenario 1 estimated the load reduction required in managed wetland sources to achieve a DO target of 5 mg/L. The existing baseline was modeled assuming the current discharge schedule, four major discharge events at 40 cfs each at two locations, and a few minor events. The results suggest that the current wetland discharge rate has to be reduced by 62% to achieve DO concentrations greater than 5 mg/L (Figure C-29). The reductions will be required during 61 days out of the 200 days modeled.

Model Scenario 2 tested the possibility of discharging the loads through a longer time period without reductions in total load. To achieve the DO target of 5 mg/L, the estimated allowed continuous daily discharge from managed wetlands is 26 cfs at current concentrations (i.e., 70 mg/L DOC, 0.1 mg/L DO). Figure C-30 shows that at this discharge rate the DO concentrations will remain well above 5 mg/L throughout the entire year.

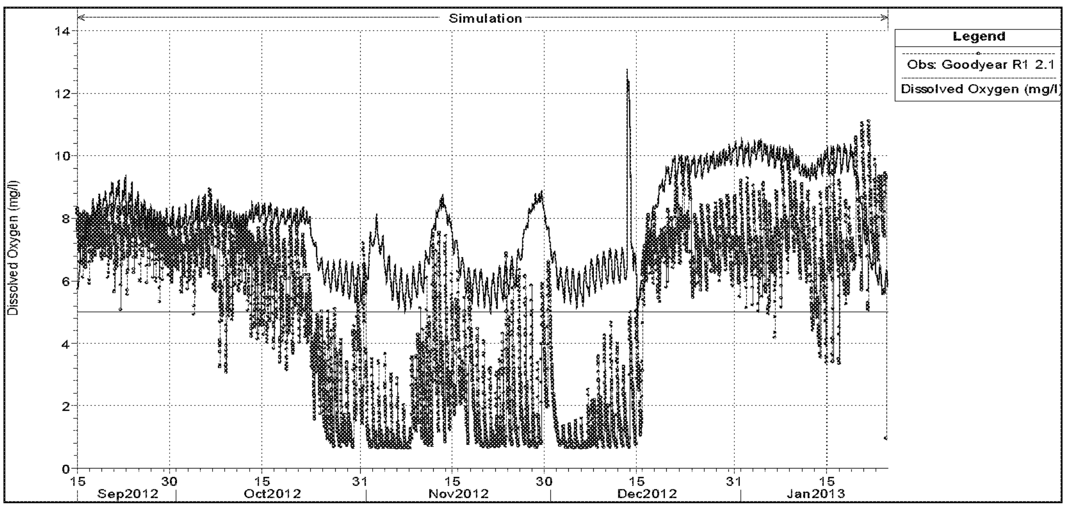

Figure C-29 Model-simulated DO concentrations in Goodyear Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

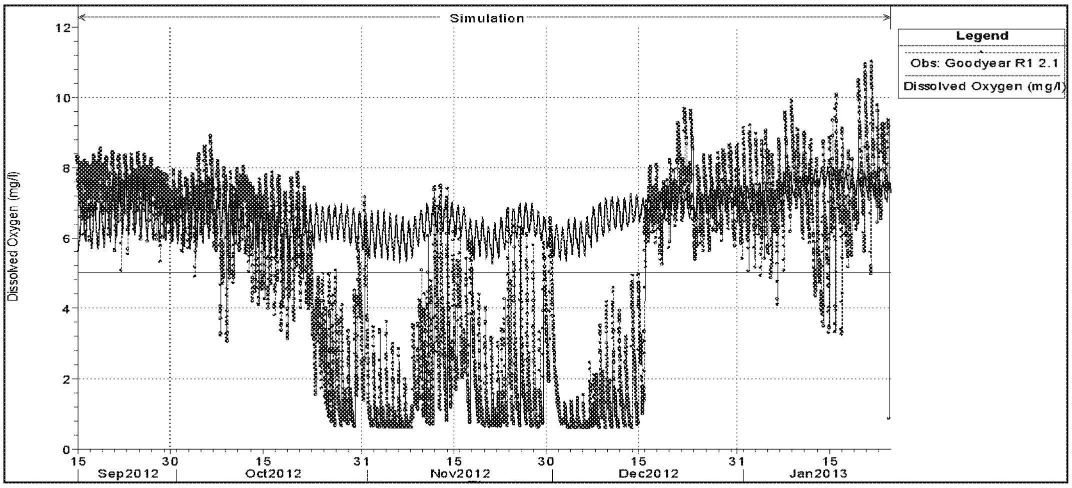

Figure C-30 Model-simulated DO concentrations in Goodyear Slough with continuous low discharge (Model Scenario 2)

Denverton Slough

For Denverton Slough Model scenario 1 estimated the load reduction to achieve the DO target of 5 mg/L. The results show that a 57.5% reduction of managed wetland discharge compared to current discharge rate and schedule will result in DO greater than 5 mg/L (Figure C-31). Under this scenario the discharge of 20 cfs from managed wetlands at current concentrations (i.e., 70 mg/L DOC, 0.1 mg/L DO) will result in DO remaining generally above 5 mg/L. There are a few incidences of low DO below 5 mg/L, however for a short amount of time (< 8 hours with DO > 4 mg/L).

Model scenario 2 tested the possibility of discharging the loads through a longer time period without reductions in total load. The results suggest that with a continuous low discharge rate of 9.84 cfs (at current concentrations, i.e., 70 mg/L DOC, 0.1 mg/L DO), DO concentrations were above 5 mg/L for the simulation period (Figure C-32).

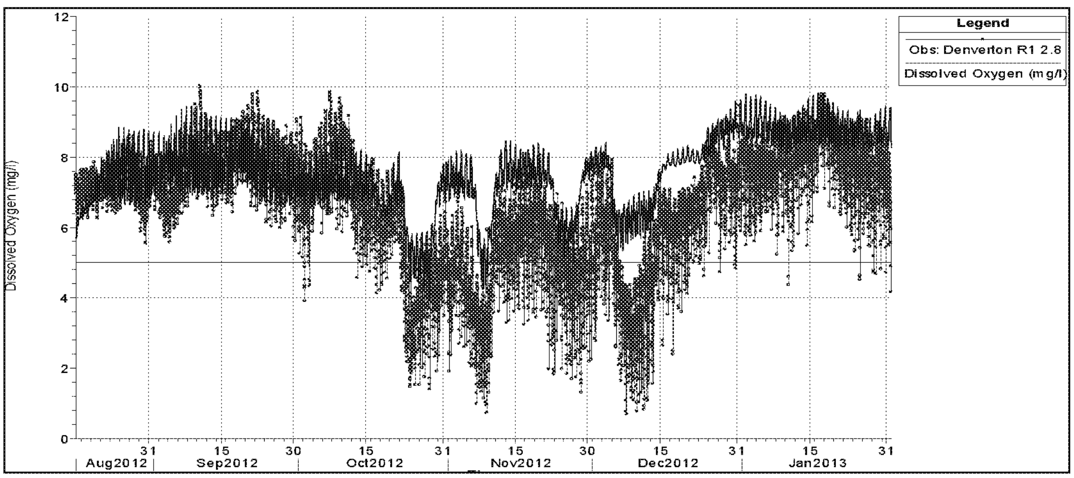

Figure C-31 Model-simulated DO concentrations in Denverton Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

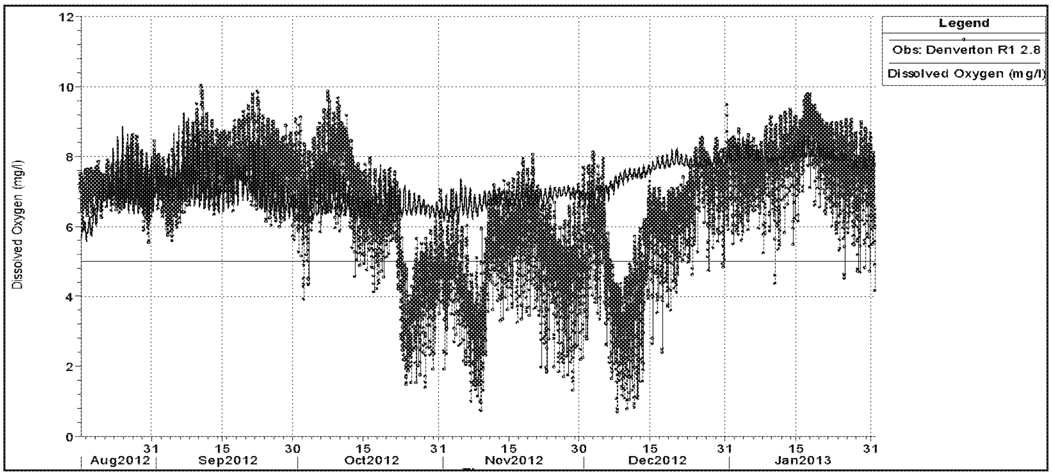

Figure C-32 Model-simulated DO concentrations in Denverton Slough with continuous low discharge to achieve 5 mg/L DO (Model Scenario 2)

Appendix C References

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ATTACHMENT

Data and Information Used in HEC-RAS Modeling

Table A-1 Discharges from Fairfield – Suisun Sewer District (Siegel et al. 2011)

Month	**FSSD**		**To Club 112**		
2007	AC-FT	AC-FT/d	AC-FT	AC-FT/d	% from FSSD
Sep	961	32			
Oct	1296	42	165	5	13%
Nov	1327	44	169	6	13%
Dec	1530	49	195	6	13%
Average	1279	42			
2008					
Jan	2089	67	111	4	5%
Feb	1818	65	128	5	7%
Mar	1701	55	90	3	5%
Apr	1157	39	0	0	0%
May	1160	37	20	1	2%
June	941	31	0	0	0%
July			45	1	NA
Aug	1092	35	5	0	0%
Sep	966	32	0	0	0%
Oct	1051	34	120	4	11%
Nov	1427	48	235	8	16%
Dec	1426	46	147	5	10%
Average	1348	44	75.1	2.5	5%

Table A-2 Wetland 123 discharge events

Date	DO Boynton (mg/L)	Wetland discharge Qave (cfs)	FSSD discharge (ac-ft/d)	Boynton Slough flow (cfs)	Temperature (ºC)
9/23/2007 (9/23/2007 – 9/27/2007)	3.5	19	32		20
2/15/2008 (2/9/2008-2/13/2008)	6.2	27	65	40-80 cfs	12.5
3/4/2008 (3/4/2008-3/07/2008)	7	41	55	40-50 cfs	13.5
9/29/2008 (9/28/2008 – 10/3/2008)	No data	34	34	0	19

Table A-3 Wetland 112 discharge events

Date	DO Peytonia	Wetland discharge Qave (cfs)	FSSD discharge (ac-ft/d)	Peytonia Slough flow (cfs)	Temperature (ºC)
10/1/07 (10/1/2007-10/3/2007)	5.7 mg/L	15	42	-20 - 40 cfs	17.5
2/1/08 (1/30/2008 – 2/2/2008)	7.7 mg/L	16	65	360 cfs	8.5
2/7/08 (2/6/2008 – 2/9/2008)	8 mg/L	10	65	60 cfs	9
2/15/08 (2/14/2008 – 2/19/2008)	7-7.2 mg/L	5	65	50 cfs	12.5
10/20/2008 (10/19/2008 – 10/22-2008)	6.8 mg/L	22	34	40 cfs	16
11/5/2008	2.9 mg/L		48	50 cfs	15

Table A-4 Comparison of Boynton and Peytonia Slough

	Boynton Slough	**Peytonia Slough**
Latitude	38’ 12.614N	38’ 13.567 N
Longitude	122’02.329 W	122’ 02.395 W
Rating curve	Area = 2.7304*stg2 + 76.278 * stg + 442.8	Area =1.9166 *stg2 + 69.45*stg + 401.5
Mean channel velocity	V = 0.8420*Index Velocity + 0.0328	V = 0.8427*Index Velocity + 0.0041
Tidal velocity (fps)	1 foot/sec (fps)	1 foot/sec (fps)
Tidal flows (cfs)	-800 cfs (upstream flow) +1200 cfs (downstream flow)	-700 cfs (upstream) + 800 cfs (downstream)
Peak ebb flows (cfs)	1500 cfs	1400 cfs
Net flow	Filling 10 – 40 cfs full/new moon, draining during lunar quarters	Filling 10 – 40 cfs full/new moon, draining during lunar quarters
Net flow	Fairly minor rainfall-runoff combined with larger spring tides	Winter positive outflows are due to watershed outflows
Wetlands	Six wetlands: Wetland 122, 123, 131, 124, 130 and 133 with a total area of 3,000 acres are connected to Boynton Slough.	Four wetlands Wetland 112, 113, 123, and 211 with a total area of 980 acres are connected to Peytonia Slough
Managed wetland discharges	Under normal operations, wetland 123 will draw water from Peytonia Slough and FSSD and discharge to Boynton Slough	
FSSD discharges	90%	10%
Sewage treatment effluent	FSSD discharges a majority of its tertiary treated effluent to Boynton Slough	A smaller discharge point exists on Ledgewood Creek in the case of high effluent flows
Tributary	Diked lands and adjacent uplands in agricultural use and containing stormwater and irrigation ditches	Ledgewood Creek
Watershed inputs	No significant watershed inputs. A portion of lowlands sod farm and the industrial areas in the northwest corner of Suisun Marsh	Ledgewood Creek (drains 11,300 acres) and unnamed open storm drain. The watershed contains agricultural, urban and open space lands

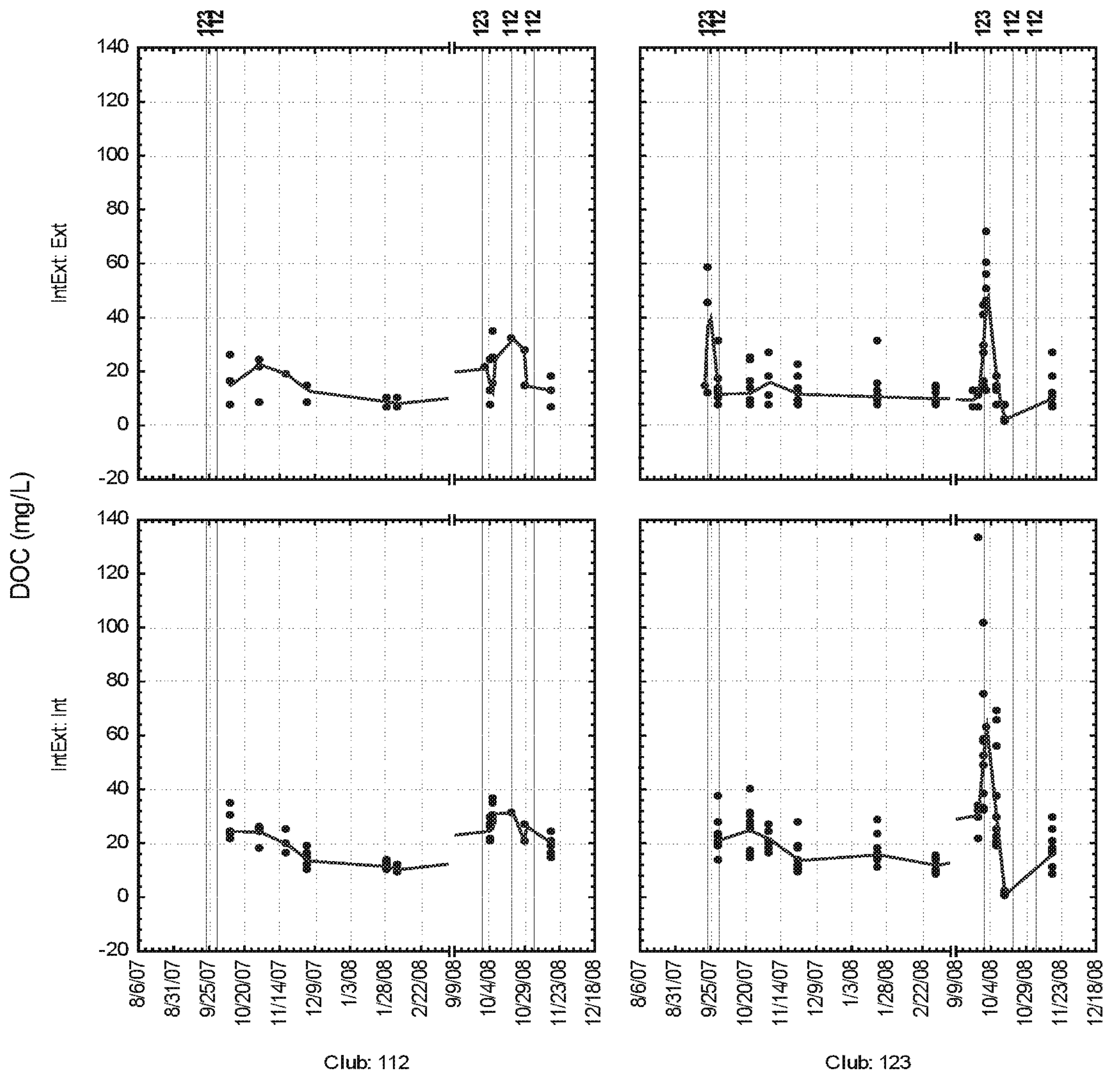

Figure A-1 Changes in DOC at Wetlands 112 and 123 perimeter and interior stations

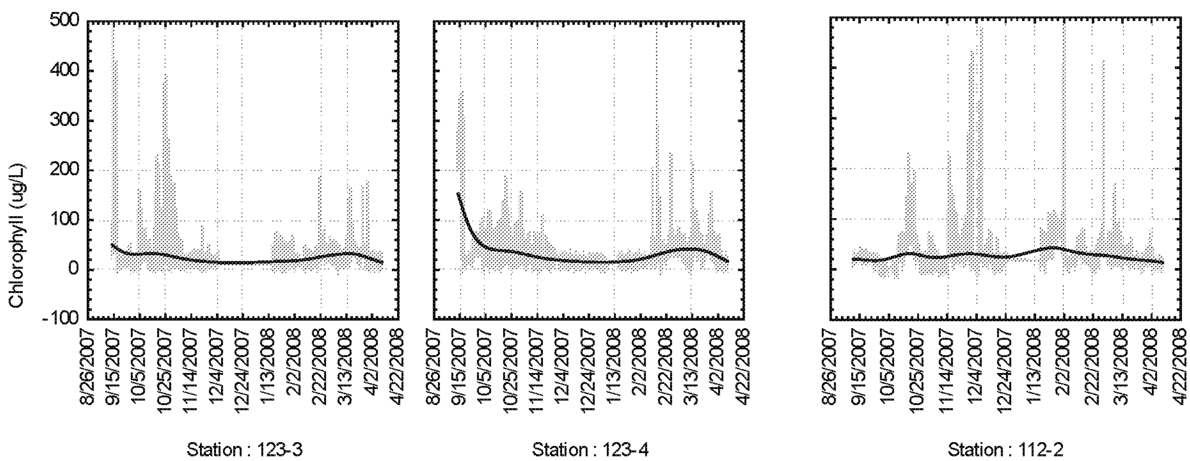

Figure A- 2 Temporal chlorophyll trends at perimeter stations for wetlands 112 and 123

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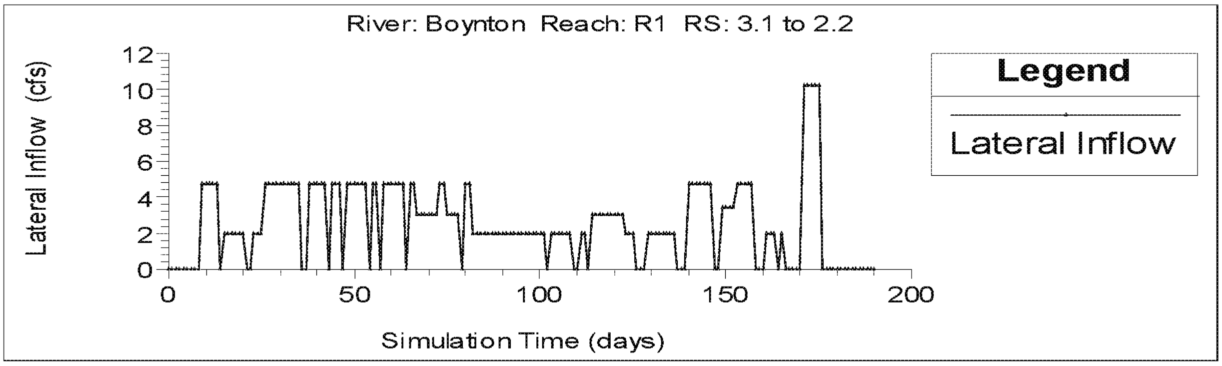

Figure A-3 Assumed wetland discharge schedule for Boynton Slough (1 out of 4)

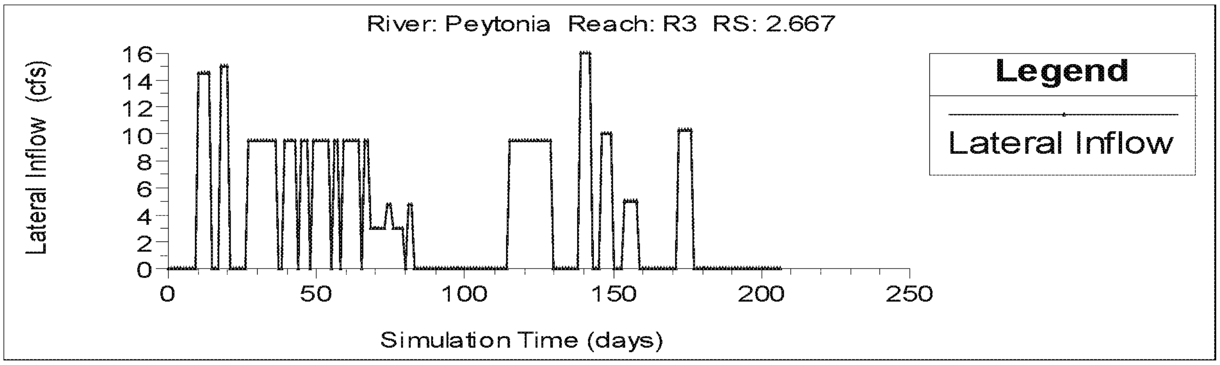

Figure A-4 Assumed wetland discharge schedule for Peytonia Slough at one location

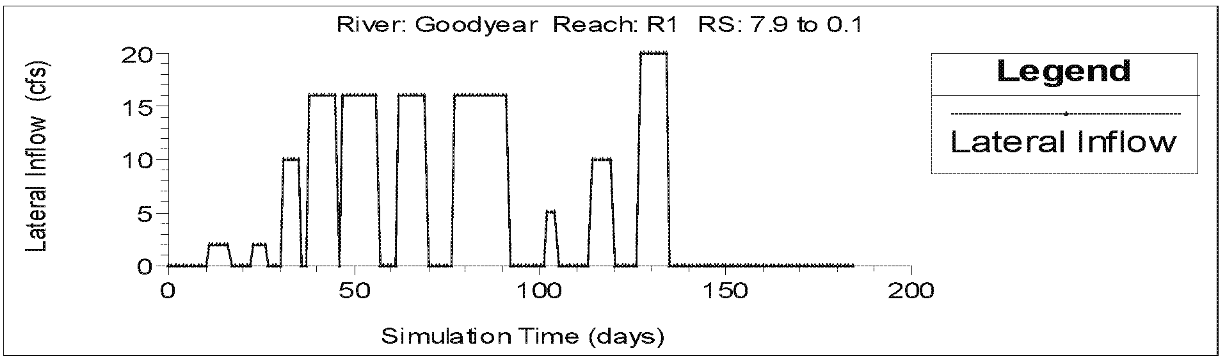

Figure A-5 Assumed wetland discharge schedule for Goodyear Slough (1 out of 4 and with a multiplier of 2.5

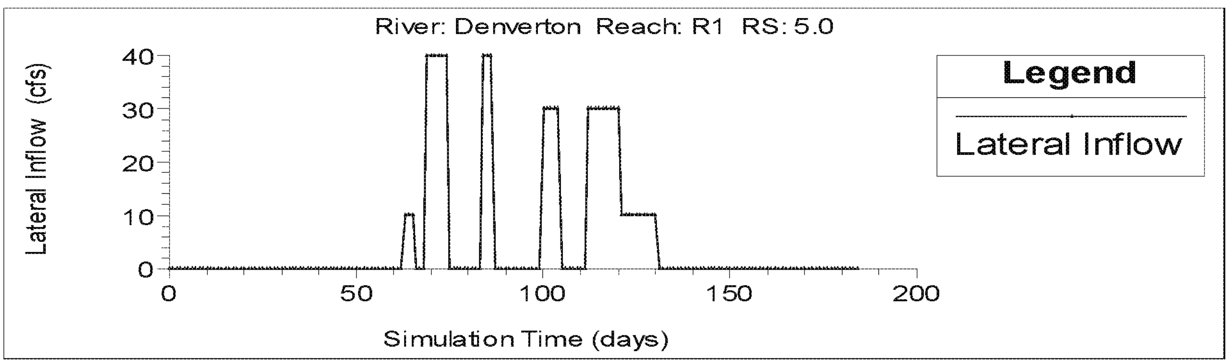

Figure A-6 Assumed wetland discharge schedule for Denverton Slough (1 out of 2)

APPENDIX D: SCIENTIFIC ADVISORY PANEL RECOMMENDATIONS FOR REFINING DO OBJECTIVES IN SUISUN MARSH SLOUGHS

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Expert Panel Review

3 May 2017

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Executive Summary

Suisun Marsh (Solano County, USA), provides habitat for many species of plants, fish, and wildlife, including rearing and spawning grounds for migratory fish and waterfowl. The marsh has been subject to many impacts over the past century (Moyle et al. 2014), including land use change, channelization of sloughs, and changes in the timing and magnitude of freshwater delivery because of water diversions upstream in the watershed, which have led to, among other issues, periodic occurrences of low dissolved oxygen (DO). An analysis supporting the development of a DO site-specific objective (SSO) was completed for Suisun Marsh, as part of the San Francisco Bay Regional Water Quality Control Board's goal of developing a Total Maximum Daily Load (TMDL) analysis for this water body. A scientific advisory panel (SAP) was engaged to review the work plan, preliminary findings and completed technical report (Tetra Tech 2017) supporting the development of the DO SSO. The Tetra Tech (2017) study consisted of four major components: 1) calculation of DO criteria (thresholds), utilizing the Virginia Province (VP) approach, 2) specification of temporal aggregation periods for acute and chronic thresholds, 3) use of reference system approach to determine allowable frequencies of non-compliance with the criteria, and 4) independent confirmation of the acute and chronic thresholds using existing fish abundance and DO data collected synoptically in Suisun Marsh (P. Moyle, UC Davis).

The purpose of this report is to summarize the findings of the SAP in reviewing the Tetra Tech (2017) study, addressing specific charge questions that were provided to the Panel by San Francisco Water Quality Control Board (SWQCB). Questions are embedded within the report below. Key findings of the SAP are highlighted and presented on these focus question issues. Additional insights are provided by the SAP in extended discussion in the report, providing greater insights into the issues. The SAP provided supporting appendices with (a) examples of statistical approaches to assessments using concepts covered during the SAP review process and information addressed in Tetra Tech (2017), (b) a survey of State applications of criteria with examples of criteria exceedance and impairment definitions using continuous monitoring data, and (c) references to literature on ecosystem recovery periods for consideration by the SWQCB. The latter is needed for determining an appropriate application period (in years) for assessing impairment of the yet-to-be determined DO standard.

Key Findings of the Expert Panel

- The SAP finds that the use of the VP approach is considered as a viable and protective technical framework for setting DO criteria.
- Application of the VP approach to Suisun Marsh supports establishment of DO criteria based on a reasonably comprehensive assessment of the available information, which considers tolerance, exposure, and growth/recruitment factors applied to representative species.
- Adequate consideration was given to the DO needs of sensitive species (e.g., salmonids) and rare and endangered species (e.g., sturgeon).
- Given that DO tolerance data for native species were largely not available, and because Suisun Marsh is a "novel ecosystem" inhabited by an established community of native and nonnative species, a focus on the DO-sensitive striped bass is appropriate.
- The frequency of allowable exceedances should be based on the ability of aquatic ecosystems to recover from the exceedances, which will depend in part on an understanding of the magnitudes and durations of the exceedances in reference conditions. This study suitably employed available monitoring data on reference sloughs to assess the frequency of allowable excursions from derived criteria; however, similar analyses should be conducted to determine the magnitude and duration of the exceedances to ensure aquatic life is adequately protected from exceedances.
- Use of DO concentration rather than percent saturation is practical for supporting the management of the resource and communication among stakeholders.
- The need to consider spatial heterogeneity in Suisun Marsh is reasonable, given the well documented variability of DO in different marsh habitats (e.g., small sloughs, large sloughs).
- The averaging period cannot be divorced from other critical aspects of the water quality standard: 1) minimum monitoring station density, 2) minimum sampling frequency and type (discrete, continuous), 3) allowable frequency of non-compliance, 4) the magnitude and duration of exceedances, and 5) the temporal averaging statistic, which should define low DO exposure risk that accounts for frequency, magnitude and duration of exceedances. Per the proposed criteria, "multiple samples" could use more explicit definition.
- The averaging period for the CMC was shown to be effective for implementation of the criterion, both as a moving average and daily mean.
- The reference-based approach provides valuable insight into the allowable exceedance frequency within years. However, following the lead of other states such as Delaware, some thought should be provided about the definition of "a violation event" that translates to an exceedance and frequency, magnitude and duration of exceedances. Further, there are multiple measures of exceedance that need to be considered: 1) the criteria exceedance rate that equates to a violation, i.e., how many violations are allowable sider a season or year as impaired, 2) exposure risk that considers magnitude and duration dimensions of exceedances, and 3) how many years can the system

experience impairment and in what period of years (3, 5, 10?) is reasonable to declare a waterway failing to meet its standard.

- Minimum requirements for monitoring were not fully defined in this process. Without a declaration of any final habitat segmentation decisions, final criteria selection, and assumptions about how representative a monitoring site is of a certain habitat area, the panel could not provide a minimum requirement. However, the panel used its understanding of the information considered during the process and provided some directions and two examples of monitoring approaches that could support monitoring and assessment needs to support the impairment decision-making process. It is essential that monitoring data treatment be adequate to quantify not only frequency of exceedance, but the risk from magnitude and durations of exceedances as well.
- We recommend collecting temperature, conductivity, and depth, along with DO. Data loggers that provide these parameters are readily available and very reliable.
- The panel is generally supportive of a 15-minute sampling frequency.
- Setting the criteria is very dependent on the needs of the living resources or the intended use. To that end, the use of diverse tools here to derive criteria (VP approach, larval recruitment model, reference system approach, biological monitoring as supporting data) provide an excellent example of application of DO criteria development concepts.

Final Questions and Responses from the Expert Panel

Q1 Please comment and provide perspectives on the methods, quality of technical analyses, and discussion and interpretation for the ability to use those findings to establish site-specific objectives in Suisun Marsh (see summary Table below), including:

a. *Protectiveness of Aquatic Life Support beneficial uses, including listed and sensitive species (salmonids, sturgeon, delta smelt, splittail), important native and introduced estuarine fishes, and marsh invertebrates;*

b. *Comprehensiveness of the Virginian Province approach, the species list, and their life history stages to derive the objectives;*

c. *Confirm the rationale for protecting salmonids when they are present (January-April)*

d. *Assumption that striped bass is sufficiently sensitive, so it's larval recruitment curve is likely to characterize conditions protective of other larval/juvenile species in Suisun Marsh*

e. *Analysis and interpretation of data on natural background DO concentrations in Suisun Marsh sloughs, and magnitude, deviation, and timing of ranges of low DO under minimally impacted conditions*

f. *Support for the concentration-based objectives rather than DO saturation;*

g. *Spatial specificity (large sloughs versus back-end sloughs).*

Protectiveness and Comprehensiveness of Approach to Supporting Aquatic Life:

Criteria should attempt to provide a reasonable and adequate amount of protection with only a small possibility of considerable overprotection or underprotection (U.S. EPA 2016). Criteria must be used in a manner that is consistent with the way in which they were derived if the intended level of protection is to be provided in the real world. Although derivation of water quality criteria for aquatic life is constrained by the ways the tests are usually conducted, the means used to derive and state criteria should relate, in the best possible way, to the kinds of data that are available concerning chronic and acute affects and the ways criteria can be used to protect aquatic organisms and their uses (U.S. EPA 2016).

The Tetra Tech study features the Virginian Province (VP) approach, selected as most appropriate to address protection of Suisun Marsh living resource and as a viable and protective technical framework for setting DO criteria. A thorough literature search of appropriate species with supporting DO data was based on the selection of diverse species that provided the best available representation of the fish community. In the absence of acute and chronic laboratory exposure data for the range of Suisun Marsh species, the VP approach provides a scientifically defensible approximation of DO tolerances suitable for protecting the Aquatic Life Use. Its application in Suisun Marsh represents a comprehensive assessment of the available information, considering tolerance, exposure, and growth/recruitment factors that were appropriately applied to the representative species.

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